Production of High Quality ^{7}Be Radioactive Beam for Nuclear Astrophysics Experiments.

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Low energy ^{7}Be radioactive beam has been produced at Nuclear Science Centre, New Delhi, using the existing 15UD Pelletron and the recoil mass spectrometer HIRA. For this purpose HIRA is operated in a new ion optical mode[1]. In this mode there is an intermediate focal plane where new slit system is installed to reject the primary beam without loosing the RIB. Optics has been experimentally tested for p(^{7}Li,^{7}Be)n reaction in inverse kinematics to produce ^{7}Be[2]. We obtained beam rejection of ~ 10^{10} at 0° with respect to the primary beam. A polypropylene $(CH_2)_n$ foil, mounted on a rotary/linear motion device, is used as production target. In the new optical mode we have unit magnification at intermediate focal plane as well as secondary target position. So beam spot size on secondary target is a replica of the primary beam spot i.e. ~ 3 mm(dia.). Purity of the RIB has been consistently found to be better than 99.9% in the energy range 11–21 MeV with yields of the order of 1kHz/pnA/mSr. Recently an LN_2 cooled gas cell has been tested as a production target. With this we expect to produce more RIBs like ^{6}He,^{8}Li, ^{8}B, ^{11}C, ^{13}N, ^{14,15}O, ^{17,18}F, ^{18,19}Ne etc. with similar quality. As many of these beams at low energies may not be available from major ISOL/Fragmentation facilities, we have the opportunity to study the nuclear–astrophysical CNO cycle reactions and also to measure precise angular distributions in near barrier transfer, fusion etc. reactions.

Recently, ^{7}Be beam was provided for a couple of experiments to measure astrophysical $S_{17}(0)$ factor using ANC method. In these experiments, we have measured angular distribution for d(^{7}Be,^{7}Be)d and d(^{7}Be,^{8}B)n reactions at E_{cm}=4.5 MeV. To our knowledge this is the lowest energy measurement of this kind.

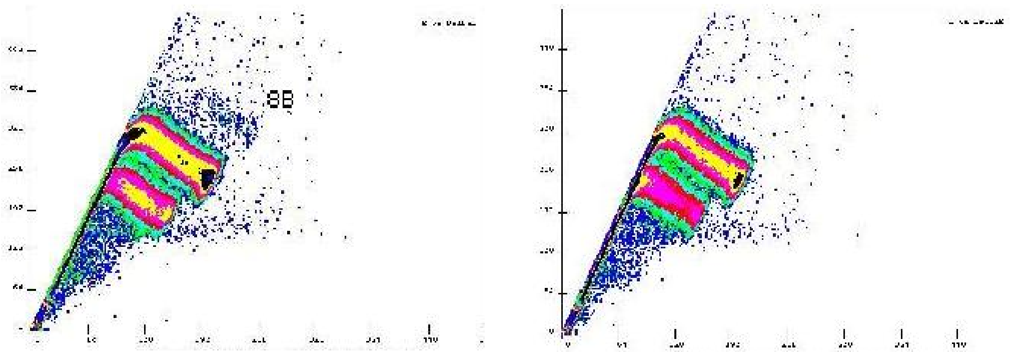

Figure 1: ΔE–E Spectra from d(^{7}Be,^{8}B)n reactions at E_{cm}=4.5 MeV. The first spectrum is measured with $(CD_2)_n$ target which shows the ^{8}B band and is not present in the other one is with $(CH_2)_n$ target

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Yield studies of nuclei in the waiting-point regions of the *rp* process at ISOLDE

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The astrophysical rapid proton capture process (*rp* process) [1] is a part of the explosive hydrogen burning occurring during astrophysical events such as accretion in a close binary system. In high temperature and density conditions of $T_9 > 1$ and $\rho > 10^4$ g/cm^2 the *rp* process can proceed beyond $A = 64$ and $Z = 32$ [2] and may continue possibly up to $A = 100$ via two-proton capture reactions bridging the waiting-points [3]. The speed of the process beyond $A = 64$ is defined largely by two of such waiting points along the process path at ^{68}Se and ^{72}Kr. Thus, experimental data on beta-decay half-lives and, in particular, nuclear masses and proton separation energies from this region are needed for reliable modelling of the process path, the resulting isotopic abundances and energy production.

In this paper we report on the status of the studies of the $N \sim Z$ nuclei close to the described bottleneck region at the ISOLDE on-line mass separator [4] concentrating on the yields of the isotopes of interest. The recent upgrade of the primary proton beam energy at ISOLDE from 1.0 GeV to 1.4 GeV was complemented by a test with 600 MeV energy at the beginning of December 2000. Particularly, the aim of this test measurement was to produce neutron-deficient Kr isotopes via spallation reactions in a Nb-foil target. In addition to their significance for near future experiments at ISOLDE, the results will possibly have significant consequences concerning the usable energies for producing the neutron-deficient isotopes in the future proton driver accelerators at ISOL facilities. A comparison of the yields to the available experimental and theoretical data will be given. In addition, the relevance of these tests for the future studies with nuclear spectroscopy and atomic mass measurements at ISOLDE [5] on the *rp* process will be discussed.

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A New ^{17}F(p,γ)^{18}Ne Reaction Rate and Its Astrophysical Implications *

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The ^{17}F(p,γ)^{18}Ne reaction is important in stellar explosions such as novae, X-ray bursts, and X-ray pulsars. This reaction influences the amount of ^{17}O and ^{18}O synthesized in novae, and is part of a crucial reaction sequence in X-ray bursts which leads to the synthesis of isotopes with mass greater than 20 and to a peak in the X-ray luminosity. It was thought that an unnatural parity, $J^{\pi} = 3^{+}$ state in ^{18}Ne provides an $\ell = 0$ resonance in ^{17}F + p capture which, depending on its excitation energy and resonance strength, could dominate the ^{17}F(p,γ)^{18}Ne stellar reaction rate at stellar explosion temperatures. This level was expected from the structure of the ^{18}O isobaric analog nucleus, but never conclusively observed despite nine previous experimental studies of the relevant ^{18}Ne excitation energy region. Calculations of the properties of this level resulted in an uncertainty of more than a factor of 100 in the ^{17}F(p,γ)^{18}Ne reaction rate.

We have observed [1,2] this missing 3^{+} state by measuring the ^{1}H(^{17}F,p)^{17}F excitation function with a radioactive ^{17}F beam produced with the isotope separator on-line (ISOL) technique at ORNL's Holifield Radioactive Ion Beam Facility. We find that the state lies at a center-of-mass energy of $E_r = 599.8 \pm 2.5$ keV ($E_x = 4523.7 \pm 2.9$ keV) and has a width of $\Gamma = 18 \pm 2$ keV. Our measurement resolves the greatest uncertainty in the reaction rate, and indicates that the 3^{+} resonance dominates the capture rate at temperatures above 0.5 GK while the non-resonant direct capture dominates at lower temperatures. Details of the measurement will be presented. Further measurements to determine the direct capture rate and the gamma-width of the 3^{+} level will also be discussed.

We have used this new rate in calculations of the nucleosynthesis occurring in nova explosions on CO and ONeMg white dwarf stars. We find that the new rate changes the abundances of some isotopes (e.g., ^{17}O) synthesized in the hottest zones of the explosion by over a factor of 1000 compared to some previous estimates, and up to a factor of 5 when averaged over zones of all temperatures [3]. Details of these nucleosynthesis calculations will also be presented.

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SIDAR: A Silicon Detector Array for Astrophysics Studies With Radioactive Beams *

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Beams of radioactive nuclei are used at ORNL's HRIBF to study nuclei and measure cross sections of interest to astrophysics. In particular, proton-rich beams are used in scattering and transfer reaction studies in order to understand important reaction rates in explosive environments such as novae and x-ray bursts. Because radioactive beams are usually of low intensity, it is important that the detector system used cover a large solid angle. Furthermore, beams are often contaminated with stable isobars, and it is therefore desirable to perform kinematically-complete measurements to distinguish the events of interest. A high-efficiency segmented detector system is a necessity to perform such measurements with a reasonable efficiency and to verify the correct kinematical relationships are satisfied. We have developed the SIDAR silicon detector array using detectors manufactured by Micron Semiconductor [1] and pulse shaping electronics from Edinburgh University [2]. We have, in addition, developed a preamplifier system in collaboration with RIS Corporation [3]. This array has been used in conjunction with a gas ionization counter in several experiments [4,5,6] with radioactive beams at the HRIBF. Design and performance characteristics of the array will be presented along with future plans.

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Determination of the ^{18}F$(p,\alpha)^{15}$O Stellar Reaction Rate *

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In the standard model of a classical nova explosion, the energy source is explosive hydrogen burning in a degenerate layer on the surface of a white dwarf star. Proton-rich β-unstable nuclei are produced, and for those with longer lifetimes (greater than 100 s), convection can carry them to the top of the envelope before they decay. The γ-ray lines resulting from decays in the envelope are, in principle, observable and would provide a rather direct test of the model [1]. The most powerful emission in gamma rays from classical novae comes at energies of 511 keV and below, which originates from electron-positron annihilation. The main contributors to positrons in nova envelopes are ^{13}N and ^{18}F. When ^{13}N decays, the nova envelope is still too opaque for γ-ray transmission; therefore, the decay of ^{18}F is the most significant for observations. The amount of observable ^{18}F which survives the runaway and is transported into the envelope is severely constrained by its destruction rate [2]. This destruction occurs most rapidly by the ^{18}F(p,α)^{15}O reaction which could be dominated by a resonance near 7.07 MeV in ^{19}Ne, depending on the resonance properties. Recent experimental results [3,4,5] have differed by as much as a factor of three in their adopted resonance strength and by as much as 21 keV in their excitation energy for this state. This results in up to a factor of three variation in the ^{18}F(p,α)^{15}O rate at stellar temperatures. We have, therefore, measured the ^{1}H(^{18}F,p)^{18}F [6] and ^{1}H(^{18}F,α)^{15}O [7] excitation functions with a thin (35-μg/cm^2) CH_2 target and a radioactive ^{18}F beam at the Holifield Radioactive Ion Beam Facility. Proton and alpha yields were measured in coincidence with the heavy recoil nuclei at 15 bombarding energies between 10 and 14 MeV. Resonance parameters for the astrophysically important 7.07-MeV state have been extracted and will be discussed. Future measurements to determine the properties of other important resonances in ^{19}Ne will also be discussed.

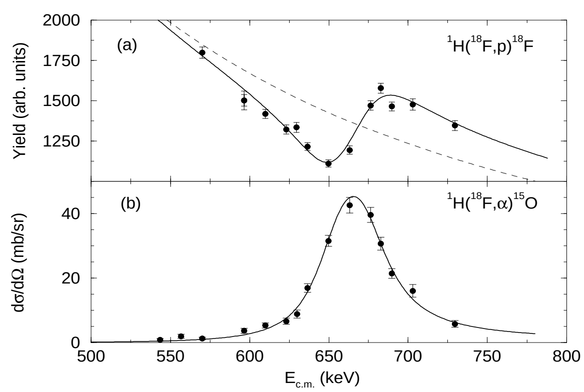

FIG. 1. A simultaneous fit of the ^{1}H(^{18}F$,p)^{18}$F and ^{1}H(^{18}F$,\alpha)^{15}$O excitation functions has been performed.

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An experimental endstation for the measurement of capture reactions with radioactive ion beams at the HRIBF*

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The fusion of protons with other nuclei provides the energy that powers many astrophysical phenomena and the mechanism for element synthesis. Under extreme conditions, such as are found in accreting binary systems like X-ray pulsars and nova explosions, the rate of proton capture by certain radioactive nuclei may exceed their rate for radioactive decay. Knowledge of proton capture rates by radioactive nuclei is needed in order to understand energy generation and nucleosynthesis in these events. Due to the relatively short half-lives for decay, direct measurement of the proton capture cross sections requires radioactive heavy ion beams on hydrogen targets. The most sensitive technique for measuring these typically small cross sections involves the use of pure hydrogen gas targets with direct detection of the recoiling heavy nuclei in a recoil mass separator [1,2]. An experimental endstation optimized for such measurements is currently being developed at ORNL's Holifield Radioactive Ion Beam Facility (HRIBF) using the Daresbury Recoil Separator (DRS) with a windowless gas target system.

The DRS is a large-acceptance recoil separator that utilizes two 1.2-m-long crossed-field velocity filters and a 50° dipole magnet to separate beam particles from the recoils of interest [3]. Reaction products are detected at the (M/Q) focal plane in a gas ionization chamber. A large-area carbon foil microchannel plate detector is currently being constructed to provide timing and position information. The DRS has been installed at the HRIBF and is being commissioned in a series of measurements using stable ion beams and foil targets. Results of these measurements will be presented.

The use of a pure gas target provides about a factor of 3 increase in yield over plastic targets for the measurement of capture reactions in inverse kinematics. A windowless gas target has been constructed for use with the DRS in measurements of capture reactions. The special compact design of the gas target includes four differential pumping stages on each side of the target. Areal densities of 3×10^{18} /cm^2 of helium have been achieved in the central target region without perceptible increases in the pressure in the fourth pumping stages, located only 0.5 m from the center of the target. Thus a high angular acceptance is achieved while maintaining the base vacuum in the nearby velocity filters. The operating parameters of the target as measured in a series of tests will be presented.

The combination of the DRS with the windowless gas target and large-area focal plane detectors provides a sensitive device for the measurement of capture reactions in inverse kinematics with radioactive beams. Plans for the first measurements with radioactive beams will also be presented.

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Nuclear Reaction Rate Uncertainties and their effects on Nova Nucleosynthesis Modeling

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The observable consequences of a nova outburst depend sensitively on the details of the thermonuclear runaway which initiates the outburst. One of the more important sources of uncertainty is the nuclear reaction data used as input for the evolutionary calculations. It has been demonstrated that changes in the reaction rates used in a nova simulation can alter the production of individual isotopes (by an order of magnitude) and change global observables such as the peak luminosity and the amount of mass ejected by 10-30% [1].

We present the first systematic analysis of the full impact of reaction rate uncertainties on nova nucleosynthesis. The use of Monte Carlo techniques allows the translation of reaction rate uncertainties into uncertainties in nova model nucleosynthesis (see Fig. 1) and thereby quantifies the extent of disagreement between theory and observations.

By examining the relative importance of changes in individual reaction rates, our analysis can provide guidance in the selection of reactions for further experimental study. We will demonstrate the usefulness of this technique by determining the relative importance of the many individual reactions involved in the production of ^{22}Na. Our analysis not only confirms the important reactions identified in [2], but also finds several additional reactions of similar importance.

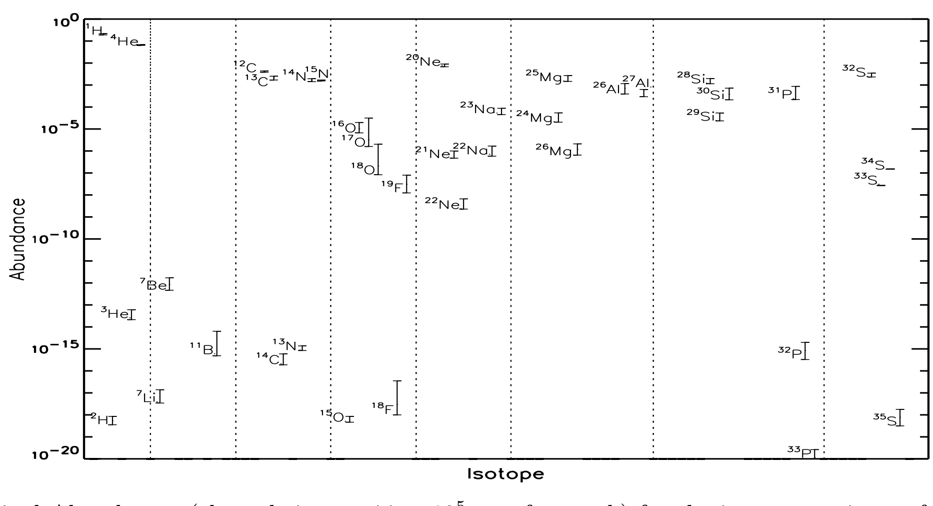

FIG. 1. Final Abundances (elapsed time = 4.7×10^{5} sec after peak) for the innermost ejecta of a model for a nova outburst on a 1.25 $M_{\odot}$ ONeMg white dwarf. The error bars are derived from our Monte Carlo analysis.

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Measurement of the ^{7}Be(p,γ)^{8}B Cross Section at the HRIBF *

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There have been many measurements of the ^{7}Be(p,γ)^{8}B reaction due to its importance in the solar neutrino problem [1]. The ^{8}B decays produce the majority of the high energy neutrinos emitted from the solar core. Those high energy neutrinos provide most or all of the solar neutrino flux detected in many solar neutrino experiments[2,3]. Persistent discrepancies between the measured flux of solar neutrinos and the predicted flux have been observed in those experiments. The solution requires either radical alterations to the theory of stellar structure or new neutrino properties [1]. Neutrino oscillations have been proposed as one possible solution.

The current generation of solar neutrino experiments will measure the flux of ^{8}B neutrinos from the sun with an uncertainty approaching 1%. A quantitative comparison of the measured neutrino flux with the standard solar model provides a rigorous contraint on neutino mixing parameters. The dominant uncertainty in the determination of these mixing parameters arises from the uncertainty in the ^{7}Be(p,γ)^{8}B reaction rate. Numerous measurements of the ^{7}Be(p,γ)^{8}B cross section have been performed using radioactive targets. However, the dominant uncertainties in the determination of the astrophysical reaction rate result from systematic uncertainties. Measurements using independent techniques are thus desired to better constrain the systematic uncertaintes. Measurements of the Coulomb dissociation of ^{8}B and the Asymptotic Normalization Coefficient for ^{7}Be+p are examples of successful approaches that have recently been applied to this problem. By combining the results obtained from numerous techniques, it may be possible to achieve the desired overall uncertainty of better than 5% in the ^{7}Be(p,γ)^{8}B astrophysical S-factor.

We plan a direct measurement of the ^{7}Be(p,γ)^{8}B cross section at the Holifield Radioactive Ion Beam Facility using a different experimental technique. The ^{7}Li(p,n)^{7}Be reaction will be used to produce ^{7}Be at the Triangle Universities Nuclear Laboratory, and the ^{7}Be particles in a metal matrix will be shipped to ORNL. After a series of chemical processes[4], a pellet containing ^{7}Be will then be mounted in a Cs sputter ion source to produce a beam of ^{7}BeO$^-$. The ^{7}BeO$^-$ will be accelerated in the 25 MV tandem accelerator and dissociated at the terminal to produce a ^{7}Be beam. The ^{7}Be beam will bombard a windowless hydrogen gas target. The windowless gas target has been constructed and is being tested. Areal densities of 3×10^{18} /cm ^{2} of helium have been achieved in the central target region. A detailed description of the ^{7}Be beam production and the gas target will be given. The DRS will be used to separate the unreacted beam particles from ^{8}B recoils. Due to the forward focusing of the inverse kinematics and the large acceptance of the DRS, the ^{8}B recoils can be detected with high efficiency. The DRS utilizes two crossed-field velocity filters and a 50° dipole magnet to separate primary beam particles from the recoils of interest. A rejection of 2×10^{-11} of scattered beam particles has been achieved in a test run[5]. The ^{8}B recoils are finally detected at the focal plan in a ionization counter which can give a further suppression of scattered beam particles. A detailed description of the experimental setup will be given.

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Excited State β-Decays the r-Process

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β-Decays of excited-state nuclei are calculated using a single-particle model, which incorporates shell energies of individual nucleons into the mass formula. Energies of two-particle levels are calculated by assuming a Fermi gas model with shell and pairing forces. A comparison of level energies to those of the spherical shell model for nuclei of the same mass yields a determination of a configuration mixture of spherical shell model eigenstates characterized by their quantum numbers. Therefore, the order of the decay is specified. The resulting density of particle states is inserted into the gross theory of β-decay, so the ease of calculation is maintained with the decay form factors. This model is quite useful in that β-decays of individual nucleons can be deduced. In addition, decays of excited state nuclei, which are created by the promotion of nucleons to levels above the Fermi surface, can be calculated with the same method. The ultimate purpose of this calculation is to determine the effects of excited-states – specifically, β-decays – on the r-process of nucleosynthesis. Since r-process progenitor nuclei are very neutron rich, decay rates must be calculated, and current models have utilized only ground-state nuclear decay rates. The possibility of a faster progression along the r-process path, as well as the possible elimination of closed-shells in a small population of the N=82 nuclei due to excitations above the shell may create an r-process simulation in which the mass 195 nuclei are produced in greater abundance by the time the r-process freezes out. An r-process model which evolves average β-decay rates as a function of temperature is used. The environmental parameters of this model simulate those of the supernova hot-bubble region, a strong candidate for the r-process site. The final freezeout abundance distribution is compared with that of the solar system r-process abundance distribution.

Tuning Effect in Nuclear Binding Energies

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Data files of experimental nuclear binding energies (E_B), mainly from AME-95 [1], and nucleon separation energies (S_N, S_{2N} etc.) together with E_B from different theoretical models (FRDM, FRLDM, RMF, ETFSI-1, HFBCS-1, KUTY) were used to study the observed in [2] stable character of intervals in binding energies (tuning effect in E_B). This effect was checked in [3-5] by observation of maxima in several distributions of ΔE_B in a broad scope of nuclei with certain combinations of differences of Z and N. Tuning effect exists only in experimental data and in Fig.1-2 some additional correlations with a period Δ=4.6 MeV found in [2] are shown.

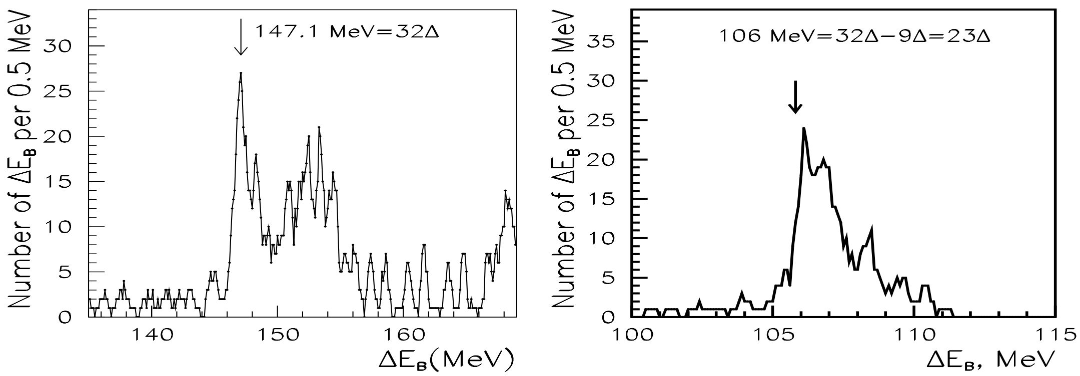

Fig.1. Differences of E_B in nuclei with ΔZ=8, ΔN=14 (left) and ΔZ=6, ΔN=10 .

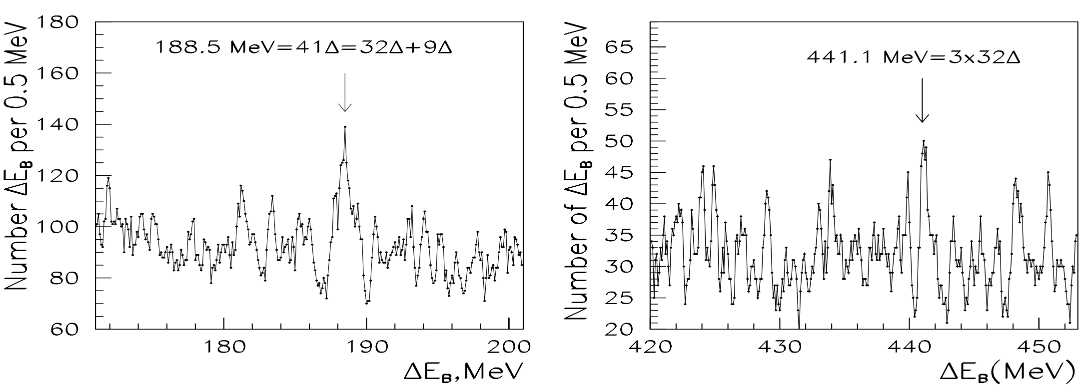

Fig.2. Differences of E_B in N-even nuclei (left) and in odd-odd nuclei [4].

The role of RIB-data in the check of the tuning effect in E_B as a phenomenon of the hadronic physics and possible connection of these effects with some unsolved problems of the Standard Model [6] will be discussed.

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DIRECT OBSERVATION AND INVESTIGATION OF CONTROLLING AND BREAKING SPONTANEOUS GAMMA-DECAY OF RADIOACTIVE NUCLEI BY THE METHOD OF DELAYED GAMMA-COINCIDENCE

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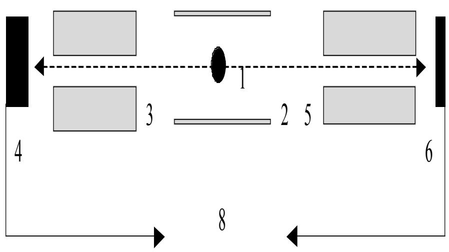
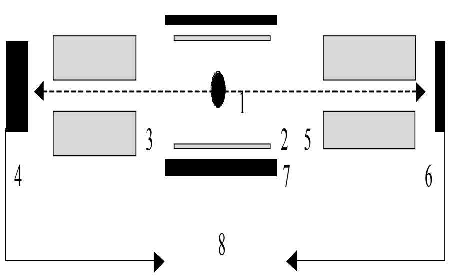
The paper discusses the theoretical model and results of direct experimental investigation of the phenomenon of controlling the probability of spontaneous gamma-decay and life-time of radioactive $Co^{57}(Fe^{57*})$ nucleus. The phenomenon of controlled nuclear decay is a result of interaction of the each excited nucleus with zero-energy electromagnetic modes, which in turn interact with the controlling and controlled thin resonant screen [1]. In our previous investigations the phenomenon of controlled decay was studied by the indirect methods both intensity [2] and spectral width [3] measurements of the emitted gamma-radiation.



The aim of the present experiment was to investigate the law of controlled gamma-decay of radioactive $Co^{57}(Fe^{57*})$ nucleus by the direct method of delayed gamma-gamma coincidence. A $Co^{57}(Fe^{57*})$ radioactive isotope with energy $h\omega_{21}$=14,4 KeV and very small activity Q=0,1 mKu was used as a source of controlled (suppressed) Mossbauer gamma-radiation 1. In the first case the source was put in the center or near the edges of the thin resonant screen 2, had a form of cylinder made of stable Fe^{57} isotope. In the second case another thick cylinder 7 made of lead was put around the resonant absorber cylinder. It totally absorbs both resonant and non-resonant radiation in the range of energies close to $h\omega_{21}$=14,4 KeV. Behind the diaphragm 3 there was an amplitude detector 4 (thick NaJ(Tl) crystal) for detecting of first quantum of decay gamma cascade with energy E_{32} = 122 KeV. Behind the diaphragm 5 there was another amplitude detector 6 (thin NaJ(Tl) crystal) for detecting the second quantum of decay cascade with energy E_{21} =14,4 KeV. The law of gamma-decay of the second transition of the cascade in the final ground state of Fe^{57} nucleus was the object of our investigation. Two signals from the detectors 4 and 6 were used for measuring of time-dependent law of gamma-decay in the processing system 8.



In the experiments we have discovered the change (increase) of radiative life-time of radioactive nucleus Fe^{57*} by 10-40 % (in relation to resonant Mossbauer gamma-channel of decay) and total life-time (including non-controlled non-Mossbauer gamma-radiation and non-controlled electron conversion channels of decay of an excited nucleus) by 1 %. For the first time the magnitude $\Delta\omega_0 \approx 10^{11}$ s^{-1} and positive sign of the radiative shift of first excited nuclear level of Fe^{57} nucleus (nuclear analogy of the electron Lamb shift) were founded in these experiments. The outcomes of the experiment correspond to the predictions of the controlled gamma-decay theory [1].

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Decay studies of proton-radioactive nuclei at the HRIBF *

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The investigations of proton radioactivity at the Holifield Radioactive Ion Beam Facility will be presented. The highlights include the identification of five new proton emitters, ^{140}Ho, ^{141}mHo [1], ^{145}Tm [2], ^{150m}Lu [3] and ^{151m}Lu [4], as well as the recent observation of fine structure in proton emission from ^{146}Tm [5] and ^{145}Tm [6]. The latter emitter was studied using a novel technique based on the digital processing of the detector signals at the Recoil Mass Separator.

The observed properties of proton emission are interpreted within a spherical approach [7,8] as well as within advanced models accounting for deformation [9,10]. These results contribute to the understanding of the structure of nuclei beyond the proton-drip line including the evolution of proton single-particle levels, nuclear shapes and energy surfaces. Recently, the $s_{1/2}$ and $h_{11/2}$ neutron levels in exotic N=77 isotone ^{145}Er were identified in the study of proton-radioactive odd-odd ^{146}Tm [5]. The transitional properties ($\beta_2 \approx 0.18$) of ^{144}Er were deduced from the 0.33 MeV excitation energy of the 2^+ level populated ($I_p \approx 9\%$) in the proton emission from the 3 μs activity of ^{145}Tm [6].

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Observation of the Gamow-Teller Resonance in Beta Decay of Neutron-deficient Nuclei near ^{100}Sn

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Neutron-deficient isotopes near the doubly magic ^{100}Sn nucleus were studied intensively during the last years, especially in terms of the problem of missing strength in Gamow-Teller(GT) β decay [1]. At GSI, we produce those nuclei by using the mass separator on-line to the heavy-ion accelerator UNILAC. As part of an ongoing research program on β decay near ^{100}Sn, we investigated ^{97}Ag and ^{98}Ag by using, as complementary spectroscopic tools, a Total-absorption Spectrometer (TAS) [2] and an array of 6 Euroball-Cluster Ge detectors (Cluster Cube) [3]. The TAS is a highly efficient NaI detector, which allows measuring the β-intensity distribution rather than the individual γ rays. The Cluster Cube represents a compromise between high resolution and high efficiency. The evaluation of TAS data depends strongly on the knowledge of the response function of the TAS for each particular cascade. The information required to obtain the response function concerns excited levels and their de-excitation patterns, which can be determined only from high-resolution experiments. Thus, the "double strategy" of combining high- and low-resolution studies provides a tool to map the GT-strength distribution to high-excitation energies in the daughter nucleus.

Based on the analysis of the Cluster Cube data [4,5], 603 γ lines (578 new) were placed in a decay scheme of ^{97}Ag, which includes 151 excited states (132 new) of ^{97}Pd, while 438 γ lines (414 new) and 173 excited states (163 new) were identified in the case of ^{98}Ag. The "peel off" method [6] was used for evaluating the TAS data. For ^{97}Ag, good agreement was achieved between TAS and Cluster Cube data, the summed GT-strengths being 3.00(40) and 2.02(40), respectively. These results are considerably higher than the value of 0.44 obtained in a previous experiment [7] using standard size Ge detectors. For ^{98}Ag, the GT strength is 2.7(4) from the TAS. However, the Cluster Cube data for ^{98}Ag still miss a considerable amount of β intensities in the high-energy region, and thus it is not appropriate to derive a GT-strength distribution directly from it.

The extreme single-particle model expects the decay of ^{97}Ag and ^{98}Ag to be dominated by the "core decay", i.e. to mainly populate, after breaking a *g9/2* pair, the 3*qp* and 4*qp* states, leading to a resonance at ^{97}Pd and ^{98}Pd excitation energies of ~4 MeV and ~5.5 MeV, respectively. This GT resonance is clearly revealed by the experiment except for the Cluster Cube data in the case of ^{98}Ag. The shell-model calculations within a so-called restricted SNB basis [8] reproduce both the centroid and the width of the GT resonance in both cases, despite a discrepancy in the summed GT-strengths. The GT-hindrance factors with respect to the TAS results amount to 4.3(6) and 4.6(6) for ^{97}Ag and ^{98}Ag, respectively, in agreement with the values expected from further configuration mixing within SNB model space. These large hindrance factors are a direct indication for the complexity of the actual nuclear wave functions compared to what one expects from the simplest single-particle shell model.

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High accuracy mass measurements of short-lived nuclides for fundamental studies with the ISOLTRAP spectrometer.

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The atomic mass is a gross property of the nuclide that embodies all the effects of the forces that are interplaying within its nucleus. Hence, high accuracy mass measurements are prerequisites for many of the past and present studies that use the nuclei as a laboratory to investigate fundamental interaction.

Examples are the tests of the Conserved Vector Current (CVC) hypothesis as well as the unitarity of the CKM matrix, which require a high accuracy investigation of superallowed β-decays. Until now 9 superallowed beta decays have been measured to very high precision. Additional interesting candidates in this context are ^{34}Ar, due to its large predicted Coulomb corrections, and ^{74}Rb, which provides a CVC test at high Z. Among others a very accurate Q-value of the β-decay of the investigated nuclides is needed, requiring precise mass values of mother and daughter nuclei.

Another example is the isobaric multiplet mass equation (IMME), that supplies a quadratic correlation between the mass and the isospin projection of members of an isospin multiplet. To test this equation, the mass of at least four members of an isospin multiplet has to be known with high accuracy. Some of these masses are ground state masses and thus accessible by direct mass spectrometry as done with the ISOLTRAP mass spectrometer.

ISOLTRAP is a Penning trap mass spectrometer installed at the online isotope separator ISOLDE/CERN. The mass separated 60-keV ion beam from ISOLDE is guided to the ISOLTRAP set-up. It consists of three main parts: (1), a linear gas-filled radiofrequency quadrupole (RFQ) trap for retardation, accumulation, cooling and bunched ejection at low energy, (2), a gas-filled cylindrical Penning trap for isobaric separation, and (3), an ultra-high vacuum hyperboloidal Penning trap for isomeric separation and the mass measurement. The mass measurement is based on the direct determination of the cyclotron frequency $\omega_c = q/m \cdot B$ of a particle of mass m and charge q revolving in a magnetic field of the strength B.

We report on mass measurements of ^{33,34}Ar, $^{73..78}$Kr, and ^{74}Rb performed with the ISOLTRAP spectrometer. ^{74}Rb and ^{33}Ar are the shortest lived nuclides ever investigated in a Penning trap ($T_{1/2} = 65$ and 174 ms). The accuracy of their mass values is governed by statistics and resolving power, that are limited by production rate and half-life respectively. The relative accuracy reached is $1.2 \cdot 10^{-7}$ for ^{33}Ar and $\leq 4 \cdot 10^{-7}$ (i.e. ≤ 30 keV) for ^{74}Rb. For the longer lived nuclides ^{34}Ar and $^{74..78}$Kr a relative accuracy of less than $3 \cdot 10^{-8}$ was achieved. This level of accuracy has never been reached before in mass measurements of short-lived nuclides. With this result the Q-value for the β-decay of ^{34}Ar could be determined with an uncertainty below 1 keV.

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Decay Properties of N≃Z Nuclei: Progress Report from the GSI ISOL-Facility

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Proton-rich nuclei, situated at or near the N=Z line between the double shell closures ^{56}Ni and ^{100}Sn, have been produced by fusion-evaporation reactions, separated by using the Isotope Separator On-line (ISOL) of GSI Darmstadt, and investigated by means of decay spectroscopy. Particular recent highlights concern the β and γ decay of the 12^+ yrast isomer in ^{52}Fe [1], and the β-delayed γ rays or protons studied for ^{56}Cu [2, 3], ^{57}Zn [4], ^{60}Ga [5], ^{61}Ga [6], the odd-odd N=Z nuclei ^{62}Ga, ^{70}Br [7], ^{94}Ag [8], and the rp-process waiting-point nucleus ^{93}Pd [9]. By combining high-resolution and total-absorption γ-ray measurements, a resonance-like distribution of the Gamow-Teller strength was found for the β decays ^{96}Ag [10], ^{97}Ag [11], ^{98}Ag [12] and $^{100-107}$In [13]. Moreover, a triple α chain was observed, which starts at ^{114}Ba and ends at ^{102}Sn [14].

These experiments have yielded either the first observation of the respective decay or considerable improvements over previous work with respect to source intensity and/or purity, detection efficiency, energy resolution and/or counting statistics. Examples for the important role of the development of ISOL ion sources and detector techniques will be given. The nuclear structure aspects of the new experimental data will be discussed, including in particular the first measurement of B(E4) values in ^{52}Fe, the new information on hitherto-unobserved β-decay branches to excited states in the core nucleus ^{56}Ni (4^+,5^+) and in the single-proton nucleus ^{57}Cu ($5/2^-$,$7/2^-$,$9/2^-$), the experimental evidence for the occurrence of long-lived (high-spin) isomers in the N=Z odd-odd nuclei ^{62}Ga, ^{70}Br and ^{94}Ag, which are of interest, e .g., for future high-precision measurements of superallowed $0^+ \rightarrow 0^+$ transitions, the shell-model interpretation of the Gamow-Teller resonance near ^{100}Sn, and the new α-decay data beyond ^{100}Sn. This discussion will take points of astrophysical relevance into account.

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Search for Physics beyond the Standard Model via a Polarization-Asymmetry correlation experiment on ^{118}Sb

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Although the Standard Model (SM) of the electroweak interaction agrees with all experimental data [1], it has too many free parameters and ad hoc assumptions to be accepted as an "ultimate" description of nature. Parity violation in particular is "explained" by the assumption that only left-handed fermions and leptons participate in the charged current weak interaction. In the description of the weak interaction, parity violation is built in by introducing the helicity projection operator $(1 - \gamma_5)$ in the Hamiltonian. Left-right symmetric (LRS) extensions of the SM, based on the $SU(2)_L \otimes SU(2)_R \otimes U(1)$ gauge group have been proposed to restore parity symmetry at high energies. Parity violation as observed at lower energies is then caused by a Higgs-type mechanism. The simplest extension of the SM is offered by the so called Manifest left-right symmetric model [2] which introduces a second charged gauge boson W_2. It acquires, by spontaneous symmetry breaking, a mass m_2 that is higher than the mass m_1 of the observed gauge boson. The two bosons are proposed to couple with the same coupling constant g to the left- and right-handed fermions with a mixing angle ζ.

$$\mathrm{W_L} = \mathrm{W_1}\cos\zeta + \mathrm{W_2}\sin\zeta \qquad \mathrm{W_R} = -\mathrm{W_1}\sin\zeta + \mathrm{W_2}\cos\zeta \tag{1}$$

From the propagators of the interaction $(\mathrm{q}^2 + \mathrm{m}_{1,2}^2)^{-1}$ it is easily seen that for $\mathrm{q}^2 >> \mathrm{m}_2$, i.e. at high energies, parity violation is restored. More general extensions [3] allow for different coupling constants and different Cabbibo-Kobayashi-Maskawa mixing matrices in the left- and right-handed sectors. In these general LRS models, experiments in β decay are complementary to μ decay measurements or to to direct searches for heavy W bosons because other combinations of parameters are probed.

We report on a recent experiment searching for right-handed currents in the ^{118}Sb nuclear β-decay that may be found in a small deviation from the full (100%) parity violation. For this purpose we have determined the correlation between the longitudinal spin polarization P and the β-emission asymmetry of the positrons from the ^{118}Sb decay. In general, the parameter P reflects the helicity structure of the weak interaction involved. When the decaying nucleus is polarized, it is possible to select the positrons that are emitted in the parity-forbidden direction. In this way the the contribution of "normal" particles associated with $\mathrm{W_L}$ is decreased while the amount of positrons coming from $\mathrm{W_R}$ is enhanced. As a result, the sensitivity of our method to right-handed currents is significantly improved. Moreover, by comparing positron spin polarization data from a polarized and unpolarized nuclear source, the measurement becomes independent of the precise knowledge of the analyzing power of the polarimeter. In this experiment the ^{118}Sb ($\mathrm{t}_{1/2}$ = 3.5m) activity was obtained as a daughter of ^{118}Te ($\mathrm{t}_{1/2}$ = 6.0d) produced at the ISOLDE isotope separator at CERN. The nuclei were polarized by means of low temperature nuclear orientation in the NICOLE on-line refrigerator at temperatures of about 8 mK. The emitted positrons were transported by an energy selective magnetic spectrometer to the polarimeter where the spin polarization of the positrons was measured by time resolved positronium spectrocopy. At the time of writing the analyses of the data is not fully completed. However, a preliminary assessment of the data indicates that a lower mass limit for the $\mathrm{W_R}$ of 350 GeV is within reach. This result makes the current experiment the best precision test of parity violation in nuclear β decay.

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Meson Exchange Current Effects studied in First Forbidden Nuclear Beta Decay in the Lead Region

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In an atomic nucleus, mesons are exchanged by the constituent nucleons . The influence of these Meson Exchange Currents (MEC) is revealed in nuclear beta decay by a strong enhancement of the time-like component of the weak axial vector current ($\int\gamma_5$) relative to its value deduced in the impulse-approximation [1]. The enhancement factor $\epsilon_{\rm MEC}$ can be determined by comparing measured ft-values of first forbidden β transitions with shell model calculations since the matrix element $\int\gamma_5$ contributes to these decays. For nuclei with A = 16 − 132 is was found that the deduced values agree with MEC calculations that are dominated by soft-pion exchange. In the lead region ($A \approx 205$–212) however, the "experimental" $\epsilon_{\rm MEC}$ is significantly larger than the value expected from soft-pion exchange models [2]. In the last decade various theoretical explanations have been proposed to explain this difference [see e.g. 4,5]. A possible difficulty with the method mentioned above is that all independent matrix elements that are involved in the decay need to be calculated, making the deduction of $\epsilon_{\rm MEC}$ susceptible to model assumptions.

Here, we report a new study of MEC in the ^{208}Pb region in which besides the ft-values, also the experimental β asymmetry parameters A_1 are used. By combining these two quantities, the rank 0 and rank 1 contributions in the decay can be separated. Because of this, only the rank 0 matrix elements have to be calculated to deduce $\epsilon_{\rm MEC}$ yielding its determination significantly less dependent on theoretical computations.

The β asymmetry experiments were performed by low-temperature nuclear orientation (LTNO) using cold on-line implantation at the NICOLE refrigerator on-line to ISOLDE at CERN and at the KOOL set-up on-line to LISOL in Louvain-la-Neuve. To reduce the influence of β scattering, β spectra were recorded with cooled (8 K) planar Ge detectors looking directly at the sample. Data were taken on the first-forbidden g.s. → g.s. transitions in ^{205}Hg $((\nu {\rm p}\frac{1}{2})^- \rightarrow (\pi {\rm s}\frac{1}{2})^+)$, ^{207,209}Tl $((\pi {\rm s}\frac{1}{2})^+ \rightarrow (\nu {\rm p}\frac{1}{2})^-)$, ^{209}Pb $((\nu {\rm g}\frac{9}{2})^+ \rightarrow (\pi {\rm h}\frac{9}{2})^-)$ and ^{213}Bi $((\pi {\rm h}\frac{9}{2})^- \rightarrow (\nu {\rm g}\frac{9}{2})^+)$. The different configurations of these nuclei allow a study of a possible state dependence of MEC. For each decay, the matrix element $\int\gamma_5$ was extracted using the newly measured A_1 parameters and known decay rate data. The new experimental data on $\epsilon_{\rm MEC}$ near ^{208}Pb will be compared with various MEC-calculations performed in the past decade [4-6] and discussed in view of the discrepancy between theory and experiment in this region [2-3].

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Isospin mixing in N ≈ Z nuclei

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Isospin impurities occur when nuclear states with $T \neq T_0$ are mixed into states with $T = T_0$. It is predominantly caused by the Coulomb interaction but possibly also by charge dependent terms in the nucleon nucleon interaction. In the N = Z region isospin mixing is enhanced because of the increased overlap between the neutron and proton wave functions. From an experimental point of view interest in isospin mixing has been triggered by the development of accelerated heavy ion beams and the production of doubly magic N = Z nucleus ^{100}Sn [1]. Here isopin mixing should increases because of the stronger Coulomb interaction in heavier nuclei. The understanding of isospin mixing is also important in tests of the Standard Model of electroweak interactions. Particular tests of the Conserved Vector Current (CVC) hypotheses and the unitarity of the Cabibbo-Kobayashi-Maskawa (CKM) quark mixing matrix use the $ft-$ values of the supperallowed $0^+ \rightarrow 0^+$ Fermi transitions which are subject to radiative (δ_R) and isospin-impurity (δ_c) corrections. Using data from [2] it is found that there is a deviation from unity by 2 to 2.3 σ, or that unitarity of the CKM matrix is excluded at the 95% confidence level [3]. A possible explanation for this situation might be found in an underestimation of the isospin mixing corrections δ_c in the determination of the dominant V_{ud} matrix element.

Theoretical calculations of $\Delta T = 1$ isospin mixing have been performed using the shell model with an empirical nucleon-nucleon interaction [4] and using the Hartree-Fock method with Random Phase Approximation [5-6]. Experimentally, isospin mixing in N ≈ Z can be determined by observing $E1$ γ decays or Fermi β transitions, both of which may vanish in the absence of isospin mixing. For $E1$ γ decay this is only the case when $N = Z$ ($T_0 = 0$). Fermi β decay on the other hand is also sensitive to isospin mixing when $T_0 \neq 0$ implying that also $N \approx Z$ nuclei can be investigated. Because isospin mixing is only appreciable in proton-rich nuclei, only β^+ decay is involved. By comparing the selection rules for allowed Fermi ($\Delta J = 0$; $\Delta T = 0$) and Gamow-Teller ($\Delta J = 0, 1$ ($0 \not\rightarrow 0$); $\Delta T = 0, 1$) β decay, it is clear that the observation of a Fermi component in a $J^\pi \rightarrow J^\pi$, $\Delta T = 1$ transition implies isospin mixing as the Fermi strength can only originate from a $\Delta T = 0$ contribution. In fact, the Fermi matrix element M_F directly yields the isospin mixing amplitude α.

Here we report on an experimental study of isospin mixing in the ground states of ^{52}Mn ($T = 1$) and ^{71}As ($T = 5/2$) via anisotropic positron emission from oriented nuclei. The β^+ asymmetry experiments were performed by low-temperature nuclear orientation. To reduce the influence of β scattering, β spectra were recorded with cooled (8 K) Si PIN diodes and planar Ge detectors looking directly at the sample. In addition, particular care was taken to ensure the purity of the radioactive sources. By combining the measured positron asymmetry parameter with the experimental $ft-$ value the magnitude of the isospin forbidden Fermi matrix element in the Gamow-Teller dominated β decay was determined. From that, the isospin mixing amplitude was deduced. Comparison with theoretical calculations show that the HF+RPA overestimate the isospin mixing probability by more than two orders of magnitude.

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Investigation of the Decay of Heavy Sn Nuclei using a Resonance Ionization Laser Ion Source*

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Recent studies on the decay of neutron-rich isotopes with A ~132, have been performed at the ISOLDE facility at CERN using a Resonance Ionization Laser Ion Source. The selectivity and ionization efficiency of this source has allowed for the study of Cu, Mn, Ag, Cd, and Sn neutron-rich species that are near subshell closure N=40 and shell closure N=82 [1,2,3]. The selectivity of the laser ionization source results from the specificity achieved from excitation and then ionization of desired products [4] that are produced from a 1 GeV proton-spallation of a UC_2 target. This ionization mechanism is accomplished by use of three dye lasers that are tuned specifically to electronic transitions of the desired products. By combining gamma, beta, and neutron spectroscopy, data were obtained for the half-lives and P_n values of ^{135,136,137}Sn. In addition, nuclear structure information was obtained for ^{135}Sb following the beta-decay of ^{135}Sn.

Heavy Sn nuclei, and all nuclei in the A~130 region are of both astrophysical and nuclear structure importance. Astrophysical ramifications involve trying to understand the mechanisms responsible for the r process abundance peak in the A~130 mass region. In order to perform accurate r-process calculations, precise measurements for β-decay half-lives, Q_β, S_n, and P_n are needed as far from the β-line of stability as possible. Improved results for r-process nucleosynthetic calculations have been obtained using β-decay half-life and P_n data for waiting point nuclei ^{129}Ag and ^{130}Cd [5].

The nuclear structure data obtained in this area is also of great interest because they allow for testing of the shell model for small numbers of particles or holes outside the Z=50 and N=82 shell closures of ^{132}Sn. Data on nuclei in this area are particularly important for comparison of microscopic nuclear-structure calculations. Studies of ^{133}Sn have already shown the difficulties of *ab initio* mean-field and HFB calculations to be able to account for the ordering and spacing of low-j orbitals [6]. The presence of low-energy $\nu p_{3/2}$ and $\nu p_{1/2}$ in ^{133}Sn, and other nuclei in various mass regions are attributed to monopole shifts of single-particle states. Theoretical studies show that this behavior can be accounted for by a reduction in the l^2 term in the Nilsson potential [7]. Other ambiguities in the theoretical models of nuclei in this region involve predictions for Gamow-Teller and first forbidden transition rates. These rates reveal important features of the structure of nuclei in the A~130 region, and also have serious implications on the development of accurate theoretical astrophysical computations. We report on the half-life and P_n values of heavy Sn nuclei and discuss the potential astrophysical and nuclear structure implications.

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Structure and Decay Properties of Heavy Zr and N = 82 r-Process Nuclides*

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The nuclear structure and decay properties of the neutron-rich nuclides with $38 \leq Z \leq 46$ with $N \leq 82$ play a critical role in determining the path of the r-process and the abundances of heavy isotopes in the A = 110 to 140 region. The most recent models for the masses of these nuclides exhibits a strong effect from the N = 82 closed shell, that, in turn, enhances the neutron capture rate relative to the photodisintegration rate for these nuclides. As a consequence of these enhanced neutron capture rates, the resulting abundances resulting from r-process calculations are found to be much lower than the observed abundances in this mass region. [1]

Subsequently, calculations derived using a reduced shell strength for the lighter N = 82 isotones showed much better agreement with the observed yields. In this paper, the monopole effects of single-particle levels for both protons and neutrons in this mass region will be discussed and the various possible sources of the shell quenching enumerated.

Finally, possible experiments that would assist in the testing of these ideas with advanced facilities will be presented and discussed.

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Decay properties of some transactinide nuclides studied with the OLGA technique

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The On-Line Gas chemistry Apparatus OLGA was applied to continuously separate transactinide elements and to analyze the products for correlated $\alpha - \alpha$ or α −sf decay chains. This technique has a typical separation time of three seconds and an overall yield of about 10 %. This permits investigation of nuclides produced with cross sections as low as 10 pb [1].
^{18}O and ^{22}Ne beams were used to bombard ^{244}Pu, ^{248}Cm or ^{249}Bk targets at the PHILIPS cyclotron of PSI as well as the UNILAC accelerator at GSI in order to form evaporation residues mainly from the 4n and 5n channels.
Besides investigation of chemical properties, the OLGA device was applied to study nuclear decay properties of the nuclides ^{263}Db, $^{265,266}Sg$ and $^{266,267}Bh$.
We will report on the measured decay properties of these nuclides that have half-lives between less than one second (^{266}Bh) and about 30 s (^{263}Db). They decay mainly via emission of α-particles and are clearly influenced by the neutron shell at N=162.
An improved version of OLGA, the IVO device (In-situ Volatilization and On-line detection) has recently been developed [2] that should give access to nuclear and chemical studies with nuclides (or elements) produced with cross sections as low as 1 pb. Two examples of future IVO applications to chemical investigation as well as nuclear decay studies will be outlined, the separation of hassium (element 108) in form of its very volatile tetroxide and of element 112 as very volatile noble metal.
Based on the high performance of OLGA or IVO set-ups such on-line chemistry separators might be well suited for future reaction studies at RIB facilities for product nuclides decaying via emission of α-particles or by spontaneous-fission.

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Probing the Structure of Exotic Nuclei by Advanced Time-Delayed Methods; Studies of μs Isomers at LISE in GANIL and RMS at HRIBF

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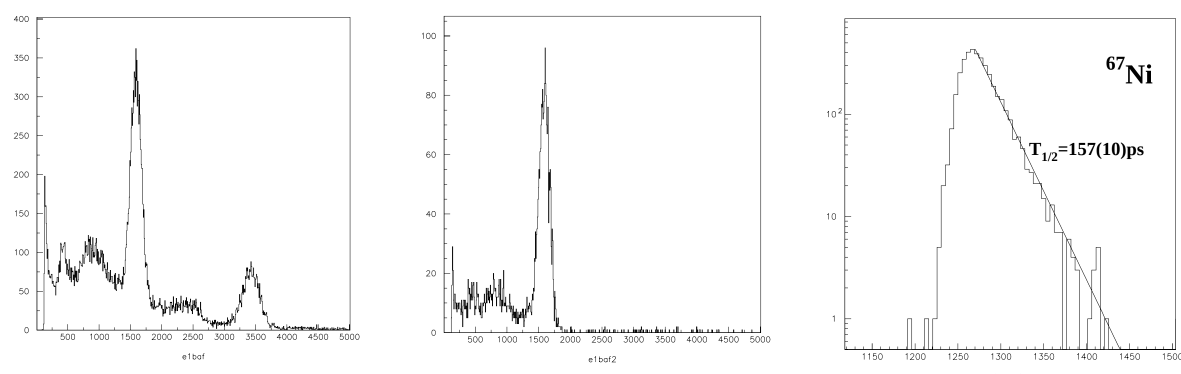
We have applied a novel time-delayed technique in order to determine lifetimes of the levels γ-fed from the exotic (and thus weakly populated) μs isomers. The measurements were performed at the LISE spectrometer in GANIL following fragmentation of the ^{76}Ge 60 MeV/u beam on a ^{9}Be target. An array of four BaF_2 detectors, which time response was precisely calibrated at the OSIRIS separator at Studsvik, was employed to search for level lifetimes from ~20 ns down to ~10 ps. The aim of the measurement was to verify theoretical structure interpretation of a few nuclei in a close vicinity of ^{70}Ni, via a strong pairing of $g_{9/2}$ neutrons. Several level lifetimes have been measured with high precision in ^{67,69,70}Ni and ^{71,72}Cu. Moreover, positions of gamma rays in the decay schemes have been also firmly assigned. The absolute transition rates provide a new level of information and more strict verification of the theoretical predictions. A preliminary result for the 694.1 keV level in ^{67}Ni is illustrated in Fig.1. A successful application of the BaF_2 array opens new possibilities for measurements of dynamic moments (via ps-lifetimes) in very exotic nuclei produced with very low intensity.

The N=Z=33 proton drip-line nucleus of ^{66}As represents one of the most interesting cases of μs isomers. Yet numerous experimental ambiguities in the knowledge of ^{66}As prevent a meaningful comparison with theoretical calculations. The time-delayed measurements, descibed above, could remove much of the existing ambiguities related to the postion of the γ rays in the decay scheme, level energies, spin/parities and the nature of the observed γ rays below the isomers. This should clarify the relative position of the low-lying T=0 and T=1 states crucial for the shell model interpretation of heavy N=Z nuclei. At present the most favourable conditions to perform the ATD measurements on ^{66}As exist at HRIBF at the Recoil Mass Separator (RMS).



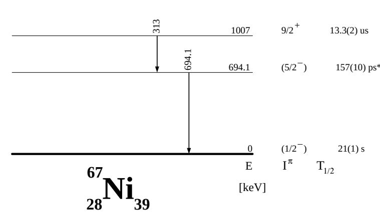


FIG.1. Left:The energy spectrum in BaF_2(det-1) showing the 313 (ch~1530) and 694 keV γ peaks (ch~3400). Middle: The coincident energy spectrum in BaF_2 (det-2) gated by the 694-keV γ-ray in BaF_2(det-1). The gate was set on the 694-keV full energy peak. Right: A time-delayed spectrum due to the 694-keV level in ^{67}Ni gated by the 313-keV (start) and 694-keV γ-rays (stop). Gates were set only on the full energy peaks.

Low Energy Tests of Fundamental Symmetries: Achievements and Prospects *

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The standard model of electroweak interactions contains a number of *ad-hoc* assumptions and poses a number of questions which are expected to find explanations in extended theoretical frameworks. There is a general consensus that, whatever the shape of the extended theory might be, new phenomena should manifest themselves either at the high energy frontier, which is accessible by exploring new energy domains, or at the precision frontier, which can be probed at any energy where precision measurements are possible.

It is well known that the nucleus is an attractive laboratory to perform precision experiments provided the involved decays are properly selected. The study of correlation observables in nuclear β-decay offer indeed simple means to perform sharp tests of the symmetry properties assumed by the standard model of electroweak interactions. More specifically, measurements of pseudoscalar observables, like the β-asymmetry parameter or the β-longitudinal polarization, and correlations involving an odd number of polar and axial vectors, constitute sensitive probes to search for deviations from maximal parity violation and from time reversal invariance in weak decays.

This paper will review such precision experiments which have made a significant progress over the past few years. In particular measurements combining the on-line production of an intense source of polarized nuclei with high efficiency polarimeters for the analysis of specific components of the β-polarization, have tested discrete space-time symmetries with unprecedent precision [1,2].

The prospects of measurements under preparation at several laboratories will be addressed with emphasis on the precision aims required by new experiments to improve present limits on non standard weak couplings.

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*Some of the achievements described in this paper have been obtained at the Philips cyclotron of the Paul Scherrer Institute, Villigen, by a collaboration between ETH-Zurich/ UCL-Louvain-la-Neuve and U.-Wisconsin (Madison) the members of which might be found in the references.

Spectroscopic studies of nuclei close to the proton drip-line in the region $Z = 30 - 38$

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During the last decade, several experiments aimed at studying neutron-deficient nuclei near or at the border of the proton drip line in the $Z = 30 - 38$ region. New isotopes were discovered and the proton drip line was indeed reached for odd-Z isotopes using projectile fragmentation [1-4] or fusion-evaporation reactions [5,6]. A recent experiment of ^{78}Kr projectile fragmentation, with the LISE (Line of Super Stripped Ions) spectrometer at GANIL [7], was performed to study spectroscopic properties of those very exotic nuclei :

1. decay of two isomers in ^{66}As [8] as well as β-decay half-life determination for some nuclei in this region [9]. These half-lives are important for the modelling of the astrophysical *rp* process and in particular for the isotope β-emitter ^{65}As, a key nucleus in the *rp* process ;
2. decay by β and $\beta\gamma$ emission of odd-odd $N = Z$ nuclei (^{62}Ga and ^{66}As), in order to determine, via their half-lives, the universal Ft value for superallowed Fermi transitions [10] ;
3. decay of $T_z = -1/2$ nuclei (^{67}Se and ^{71}Kr) by delayed βp emission to improve half-life and proton branching ratio measurements, as well as to seek for a ^{71}Kr isomer-to-be [11-14] ;
4. the very first measurement of half-lives and decay properties of ^{60}Ga and ^{64}As to find out if they are proton emitters (they would be then the lightest ones known to-date) or β emitters (which would open new paths for the *rp* process), and also obtain more accurate data on ^{61}Ga et ^{65}As,

the last results will be presented here.
The detection apparatus consisted of a silicon telescope, including a silicon strip detector (for x-y measurements) where the ions were implanted and their following decays observed while keeping track of the correlation between nuclei identification and radioactivity. High efficiency germanium detectors surrounded the silicon telescope.

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Rearrangements in Neutron Shell Closures of Very Neutron-Rich Nuclei

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The study of the properties of extremely neutron- or proton-rich nuclei of light elements is a very important topic in the modern nuclear physics. The research in this field has revealed a halo and skin structure and other unique features that could result in the modification of magic numbers in very neutron-rich nuclei. A breaking of magicity has already been observed at the N=20 shell closure where an "island of inversion" in shell ordering has been shown to exist. Though some theoretical calculations predict the existence of new magic number N=16 [1], until recently no experimental evidence about magic numbers, substituting N=20, was available. Recently, we have presented a review [2] of experimental results obtained at GANIL suggesting the appearance of new magic number, N=16, in this region. Our finding was based on the following experiments.

An experiment on the LISE3 spectrometer, where we used the fragmentation of the neutron-rich projectile ^{36}S to produce and study very neutron-rich nuclei in vicinity of doubly magic ^{28}O [3]. No events were observed corresponding to oxygen isotopes ^{25,26,27,28}O and also to ^{24,25}N. It should be noted that the instability of ^{25,26,27,28}O and ^{24,25}N was also confirmed by Sakurai et al. [4] where, however, a new isotope, ^{31}F, was observed for the first time. Thus the heaviest experimentaly found isotopes of C, N and O have the same neutron number, N=16, while the heaviest isotope of fluorine was found to be ^{31}F with N=22.

The question of particle stability is directly related to the masses and nuclear binding energies, which are very sensitive to the existence of shells and may provide clear signature of shell closures. Therefore, an experiment on the mass measurement using a direct time of flight technique [5] was undertaken in order to investigate the N=20 and 28 shell closures for nuclei from Ne to Ar and thus to shed some light on the behaviour of magic numbers far from stability.

The nuclei of interest were produced by the fragmentation of a 60 AMeV ^{48}Ca beam on a Ta target. The separation energies of two last neutrons S_{2n} derived from the measured masses were plotted versus neutron number. The Ca, K and Ar isotopes show a behaviour typical of the filling of shells, with the two shell closures at N_{sh}=20 and 28 being evidenced by the corresponding sharp decrease of the S_{2n} at these points, and a slowly decreasing S_{2n} after the "flattening" point $N_f=(N_{sh}+2)$ as the filling of the next shell starts to influence S_{2n}. The "flattening" point of the slope at N_f=22, corresponding to the existence of the shell N_{sh}=20, is clearly visible for Si-Ca region, while going to lower Z into the Al-Na region this point seems to move towards to lower N till it stabilizes at N_f=18 (new shell N_{sh}=16) for F and Ne.

Thus the behaviour of the "flattening" points in the S_{2n} values gives a very clear evidence for the existence of the new shell closure N=16 for Z=9 and 10 appearing between $2s_{1/2}$ and $1d_{3/2}$ orbitals. This fact strongly supported by the instability of C, N and O isotopes with N $>$ 16, found in refs. [3,4], confirms the magic character of N=16 for the region 6$\leq$ Z $\leq$10, while the shell closure at N=20 tends to disappear for 6$\leq$ Z $\leq$13. This is in a good agreement with recently published work of Ozawa et al. [6] where the similar information on the magicity of N=16 was obtained from S_{1n} values and σ_I.

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Two-proton radioactivity as a genuine three-particle decay: the ^{19}Mg probe.

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Two-proton emission, the specific case of three-particle decays, may be described by two complementary mechanisms: the sequential emission of protons via an intermediate state, and the simultaneous, or direct, emission of protons. The first mechanism includes also the model of emission of "diproton", or a ^{2}He cluster with very strong *pp*-correlations. This model is traditionally associated with the two-proton radioactivity, [1], which is unobserved yet.

In the Ref. [2], a two-proton emission has been considered for the first time in a realistic three-body model. This approach is suitable for treatment of a genuine three-particle decay, where resonances in the binary subsystems are located at higher energies than in the three-body system, and the emission process is non-sequential. This situation is similar to the "borromean" property of bound halo nuclei (e.g. ^{6}He, ^{11}Li, ^{17}Ne). Genuine three-body decay modes are known for several states in light nuclei, e.g. ^{6}Be [3], ^{9}Be* [4], ^{12}C* at 15.11 MeV [5]. The model is applied to candidates for the two-proton radioactivity, the ^{19}Mg and recently discovered ^{48}Ni [6], which are likely to be bound to single proton decay but unbound to two-proton decay.

The results of the calculations predict 1000 times larger life-times of ^{19}Mg and ^{48}Ni than the traditional diproton model, e.g. up to 100 ps for ^{19}Mg. Specific observable, p-p correlations following the ^{19}Mg decay, differ drastically in predictions of these models as well. The strong *pp*-correlations which exist in the interior of the nuclei are significantly smoothed in asymptotic by the proton pairing and Coulomb interactions.

We discuss the comprehensive experiment, in which a possible radioactivity of ^{19}Mg might be studied as its decay in flight by invariant mass method detecting all three fragments in the ^{17}Ne+p+p coincidences. The specific *pp*-correlations as well as mass excess and life-time of the ground state of ^{19}Mg can then be obtained. The ^{19}Mg life-time may be derived from the measured decay vertex distribution. Then a precise determination of all fragment trajectories is needed that can be achieved by microstrip detectors. We show that such an experiment could be performed using the radioactive beam of ^{20}Mg, [7].

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Levels scheme of ^{147}Eu

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In presents work the energies and relative intensities of gamma rays, k conversional electrons and X_k-rays have been determined with high accuracy. Also multipoles of the following transitions were defined: 297,02(M1,E2); 341,31(E1); 346,28(M1); 506,59(M1,E2); 529,95(M1,E2); 882,09(M1,E2); 983,41(E1); 1399,25(M1,E2); 1676,33 keV (M1,E2).

As a results of analysis of the spectra of positrons two components $E_{\beta_1^+} = 1160(13)$ and $E_{\beta_2^+} = 933(5)$ keV have been given off. At this point $Q_{\beta^+} = 2185(5)$ keV. The new coincidences of K 229,29 with transitions: γ778,04, γ1232,76, γ1566,34, γ1586,80 and γ1676,33 keV were observed.

The spectra of gamma rays, internal conversion electrons (IWC), positrons and eγ-coincidences have been analysed and on this base the ^{147}Gd→^{147}Eu decay scheme was constructed. New levels were introduced in the decay scheme: 1007,40; 1337,70; 1771,94; 1816,06; 1816,46; 1838,82; 1874,69; 1905,05 and 1965,64 keV.

The existence of this levels, which were introduced earlier by assumption, is proved by the analyses of eγ-coincidences. The quantum characteristics (I^{π}) of level 1474,57 keV were determined. In work the levels scheme of ^{147}Eu is discussed in detail.

PROPERTIES OF SAMARIUM (A=145,147,149) ODD ISOTOPES NUCLEI

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Values of spins of main states (I=7/2) in accordance with the cover model can be interpreted as states of odd neutron $2f_{7/2}$. An analysis of main and low located excited levels of samarium odd-neutron nuclei with N=83,85 and 87 shows that the levels $3/2^-$ of N=83 nuclei are located higher than those for N=85 nuclei. Analogous behavior is observed for states $5/2^-$ while transition from N=85 nuclei to N=87 ones.

^{145}Sm nucleus has one neutron over filled N=82 cover. The energy of first excited state has high value (893,74 keV, $3/2^-$). Calculations using single-particle model well describe characteristics of the following states: 0 keV ($2f_{7/2}$), 893,74 keV ($3p_{1/2}$) and 1423,22 keV ($1h_{9/2}$) in ^{145}Sm.

^{147}Sm nucleus has three neutrons over a closed cover. The energy of first excited state 121,25 keV ($5/2^-$) is abruptly decreased.

^{149}Sm nucleus has five neutrons over filled N=82 cover. First excited level of ^{149}Sm ($5/2^-$) is analogous to corresponding level of ^{147}Sm ($5/2^-$). The following levels 277,08 keV ($5/2^-$) and 350,00 keV ($3/2^-$) of the ^{149}Sm, probably, have multi-particle configuration. Values of lgft of corresponding β-transitions to these levels (8,4 and 8,2) allow one to make a conclusion that their wave-functions contain admixtures of a state which is described by $1h_{9/2}$ orbit, β-transition to the last is forbidden in accordance with l quantum number.

Even-even spanning set of ^{149}Sm is a nuclid of ^{148}Sm, which is soft for surface vibrations. That’s why level 528,48 keV ($3/2^-$), probably, in accordance with quasiparticle-phonon model has the admixture of quasiparticle components in sub-covers $f_{7/2}$, $f_{5/2}$ (these levels are energetically close) plus phonon $Q_1(2)$.

It is difficult to tell anything concrete about property of 558,41 keV ($5/2^-$) level. Values of lgft for β-transition to this state point out to either multiparticle configuration with strong component of $h_{9/2}$ orbit, or appearance of noticeable deformation.

As a whole, the model rather well describes the structure of levels for these nuclei.

PROPORTIES OF ODD ISTOPE ^{147}Eu NUCLEUS

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Spectra of γ-rays and electrons of internal Conversion (EIC) in the process of ^{147}Gd $\rightarrow$^{147}Eu decay have been investigated. A number of new unsufficiently intensive gamma-transitions was revealed, and they were placed into the decay scheme:

Gamma-transitions of ^{147}Eu

In previous papers the basic experimental results, connected with the investigation of K_x-, γ-radiation, electrons of internal conversion (EIC) and spectra of positrons (β^+) were published.

The present paper reports on new data and analysis of spectra of γ-rays, EIC and positrons. There revealed a number of new unsufficiently intensive γ-transitions, and a part of them is placed into the scheme of ^{147}Gd $\rightarrow$^{147}Eu decay.

Experimental values of the coefficient of internal conversion (CIC) were compared with the theoretical calculations, and multiplicities of ^{147}Eu γ-transitions were identified. In the process of calculation of an error in determination of a relative intensity of K-conversion electrons, gamma-rays, and a coefficient of scale connection. As a result, we determined the multiplicities of the following unsufficiently intensive transitions:

E_γ (ΔE_γ), keV	I_γ (ΔI_γ)	I_k (ΔI_k)	α_k ($\Delta\alpha_k$)	σL	E_i	E_f
	arb. units					
537,68(8)	0,15(3)	-	-	-	-	-
548,78(6)	0,14(2)	0,018(5)	0,019(6)	M1,E2	-	-
647,01(1)	0,12(2)	-	-	-	-	-
737,45(12)	0,10(1)	0,003(1)	0,045	M1,E2	1806,55	1069,246
751,81(13)	0,28(4)	0,024(7)	0,013(4)	M1	1874,69	1122,714
834,58(6)	0,021(7)	-	-	-	1696,30	861,640
918,15(24)	0,07(2)	-	-	-	-	-
936,98(23)	0,06(1)	-	-	-	-	-
948,29(5)	0,16(1)	-	-	-	-	-
976,8(3)	0,042(8)	-	-	-	1838,82	861,646
1017,85(4)	0,18(1)	-	-	-	-	-

The obtained results are original. In this paper we discuss the quantum characteristics of the excited states of ^{147}Eu nucleus.

A Digital Spectroscopy System for Charged Particle Studies at the RMS

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We have installed and commissioned a digital flash ADC electronics system for proton decay studies using the Double Sided Strip Detector (DSSD). This new system is based on the Digital Gamma Finder (DGF-4C) units produced by X-ray Instrumentation Associates (XIA) [1]. This system involves fitting the preamp signals via the on-board processors. The signal from the high energy recoil takes several tens of μsec to fall to the baseline, fast decays will then appear as a small "pileup" signal on top of the larger signal. By fitting the two signals, we are able to observe decays within ~500 nsec of implantation with a low-energy threshold of less than 300 keV.

Two modes of operation have been developed for the acquisition: "Standard Mode" and "Proton Catcher Mode". In the standard mode, signals from the preamps are analyzed and time stamped by the processors contained in the modules. Each event contains the energy amplitude of the signal and the time when it occurred. The proton catcher mode accepts only those events that occur within 10 μs of each other. In this mode, the processors record the entire signal waveform, which contains both the first (larger) recoil signal , and the second (smaller) decay signal lying on top of it.

The "proton catcher" mode has been used in several searches for short-lived proton emitters, and fine structure studies of ^{145}Tm [2]. The use of our new digital system has resulted in an order of magnitude gain in the rate for this short-lived isotope (3 μs) over previous work [2] performed at the Holifield facility.

[1]. M. Momayezi, *et. al.*, Proceedings of International Symposium on Proton-Emitting Nuclei, Oak Ridge, Tn, 1999, (ed. J.C. Batchelder), AIP **518**, 307 (2000).
[2]. M. Karny, *et. al.*, to be published.
[3]. J. C. Batchelder, *et. al*., Phys Rev C **57**, R1042 (1998).

E1-Resonances in Neutron-Rich Nuclei

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The photoabsorption and electromagnetic (EM) E1 differential cross sections of for oxygen and calcium isotopes are calculated within the phonon damping model (PDM) [1] including the superfluid pairing correlations. Clear pygmy dipole resonances (PDR) are seen in the EM cross sections in ^{18,20,22,24}O and some very neutron-rich calciums (^{50,52}Ca). The present work demonstrates that the EM differential cross section is a better probe for the PDR as compared to the photoabsorption cross section because, in the former, the low-energy tail of giant dipole resonance (GDR) is enhanced. It also shows that, using low-energy beams at around 50 – 60 MeV/n, one can separate PDR peaks out of admixture with the GDR in the EM differential cross sections. An example for the energy-weighted sums (EWS) of pygmy dipole resonance's (PDR) strength is shown in Fig. 1 for oxygen isotopes, where the results of calculations within PDM are compared with the preliminary experimental systematic [2] and the prediction by the cluster model sum rule (CRS).

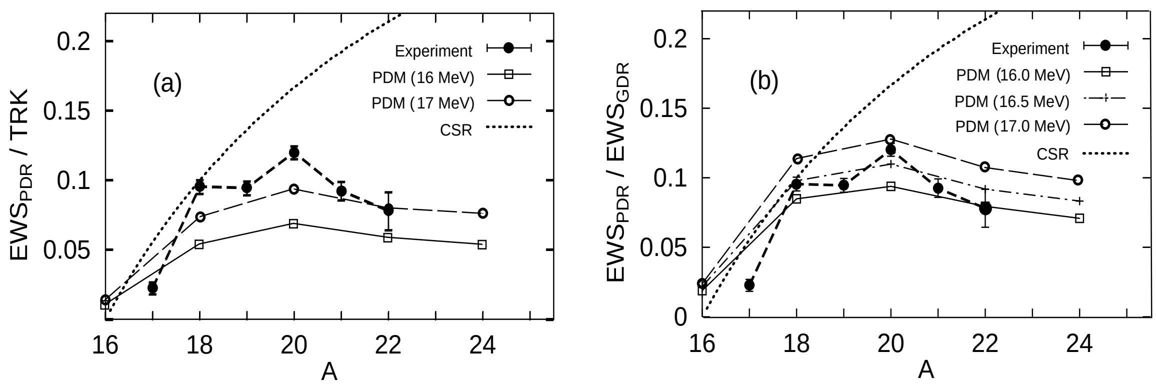

FIG. 1. EWS of PDR strength up to excitation energy $E_{\max}$ for oxygens. Results obtained within PDM with $E_{\max}$ = 16, 16.5, and 17 MeV are displayed as open boxes connected with solid line, crosses connected with dash-dotted line, and open circles connected with thin dashed line, respectively. The PDM results are shown in units of Thomas-Reich-Kuhn sum rule (TRK) in (a), and in units of the total GDR strength integrated up to 30 MeV in (b). Experimental data (in units of TRK), obtained with $E_{\max}$ = 15 MeV, are shown by full circles connected with thick dashed line. The dotted line is the prediction by CSR (in units of TRK).

[1] N. Dinh Dang and A. Arima, Phys. Rev. Lett. **80** (1998) 4145, Nucl. Phys. **A 636** (1998) 427.
[2] T. Aumann et al., GSI scientific report 1999 (GSI 2000-1, March 2000) 27.

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High-Spin Spectroscopy Near ^{56}Ni*

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High-spin studies in the nuclear region around ^{56}Ni haven been topical for several years now. Benefiting from powerful detection devices, impressive results have been obtained such as the observation of highly and superdeformed rotational bands in second (or third) minima of Ni, Cu and Zn nuclei [1-3]. In a recent 2-day experiment using Gammasphere, the Microball, and the new Neutron Shell (30 liquid scintillator counters) [4], we have studied the evaporation residues in the ^{32}S + ^{28}Si $\rightarrow$ ^{60}Zn* reaction at 130 MeV. Some highlights of our findings are summarized below.

In ^{57}Ni (2pn channel) and ^{57}Co (3p), highly deformed rotational bands are newly observed [5]. The bands in ^{57}Co, which are signature partner bands, are particularly interesting. Their observation extends the mass 60 region of large deformation below Z = 28 and provides an important test for the picture of particle-hole excitations across this shell gap. Their magnetic properties (B(M1) values for the interband transitions) are discussed in the context of possible configuration assignments. The features of the new bands are theoretically described by Skyrme Hartree-Fock calculations.

The level schemes for the N = Z nucleus ^{54}Co (αpn) and its neighboring isotope ^{56}Co (3pn) have also been extended significantly towards higher spin. The newly observed states are exclusively located in the first, spherical minimum. Calculations to obtain a shell model description for these states are under way.

A follow-up experiment will enable us to study the products from the ^{60}Zn* compound system with higher statistical accuracy. First results from this experiment should be available by the time of this conference.

[1] C.E. Svensson et al., Phys. Rev. Lett. **79**, 2104 (1997).
[2] D. Rudolph et al., Phys. Rev. Lett. **80**, 2104 (1998).
[3] D. Rudolph et al., Phys. Rev. Lett. **82**, 2104 (1998).
[4] http://wunmr.wustl.edu/~dgs/NeutronShell.
[5] W. Reviol et al., Nucl. Phys. A, in press.

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Gamma ray spectroscopy using radioactive beams at Notre Dame

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Gamma ray spectroscopy has been performed from fusion evaporation reactions produced by a radioactive beam of ^{6}He on a Copper target. Only one other radioactive beam spectroscopy experiment has been published to date [1] making this a state of the art apparatus. There are consequently many experimental difficulties to overcome in the design of any such facility, and these will be discussed.

The radioactive beam facility at the University of Notre Dame nuclear structure laboratory [2-4] was used to produce a beam of ^{6}He at an energy of 28 MeV and with an intensity of 5×10^{5} pps. This radioactive beam was produced by 1 proton transfer from a ^{7}Li primary beam on a gas cooled ^{9}Be target. The secondary beam was separated from non-reacting primary beam using the 'Twinsol' dual superconducting magnet apparatus, and was then incident on a target of natural (63% ^{63}Cu) copper. Two large volume HPGe detectors were used to detect gamma rays from excited states in the secondary fusion evaporation reaction fragments, and coincidence spectra will be presented.

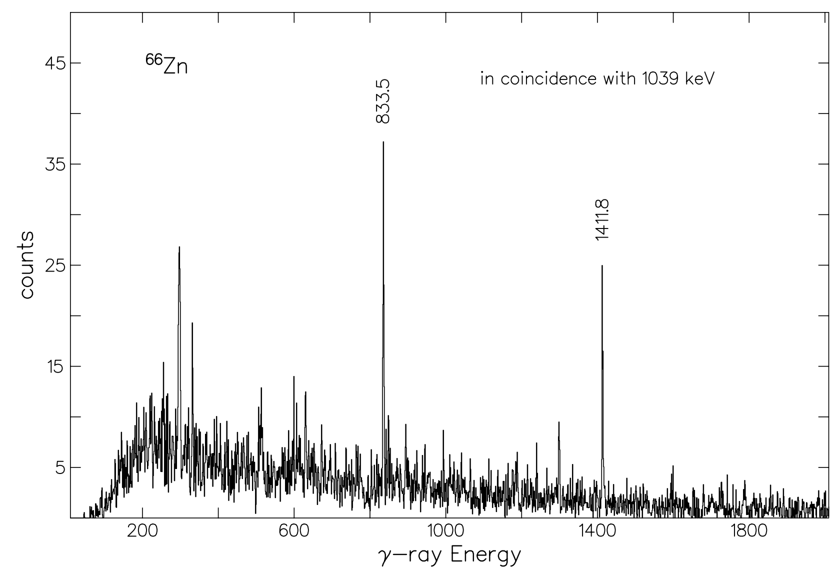

FIG. 1. Coincidence spectrum from reaction of radioactive ^{6}He on ^{63}Cu, gated by $2^{+}\rightarrow0^{+}$ in ^{66}Zn.

[1] W. Catford *et al.*, Nucl. Instr. Meth **A371** (1996) 449

[2] J.J. Kolata, A. Morsad, X.J. Kong, R.E. Warner, F.D. Becchetti, W.Z. Liu, D.A. Roberts, J.W. Jänecke, *Nucl. Instr. Meth. Phys. Rev. Sect.* **B40/41**, 503 (1989).

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New Transitions Found in ^{27}Na Using a ^{14}C Beam on a ^{14}C Target *

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Until recently it has been difficult to study nuclei that do not lie near the line of stability. Due to the recent developments in radioactive beams, it has become increasingly important to study the structure of nuclei in *s-d* shell region. At present, very little is known about the structure of the neutron rich *s-d* shell nuclei. The study of nuclei in this region would prove invaluable in comparing microscopic and macroscopic nuclear models.

Previous studies of the *s-d* shell nuclei have resulted in observation of several transitions in ^{25}Na [1], but very little in the other Na nuclei further from the line of stability. However, advances in radioactive beams and detectors make it important to re-examine the nuclear structure of these Na nuclei and other nearby nuclei, which may also help in the study of more neutron rich nuclei.

Several new transitions in ^{27}Na were found using the ^{14}C(^{14}C,p) reaction at E_{lab} = 22 MeV. The ^{14}C target was 0.28 mg/cm^2 thick and the beam was stopped in a 33.8 mg/cm^2 Au foil. γ-γ, particle-γ, and particle-γ-γ coincidences were measured using 2 four-crystal Eurogam type "clover" detectors, 7 Compton suppressed HPGe detectors, and a particle E-ΔE telescope at 0°. The 67, 1660, 1756, 1823, and 2219 keV transitions, which are in coincidence with the high energy protons, have been identified as transitions in ^{27}Na, as shown in Fig. 1.

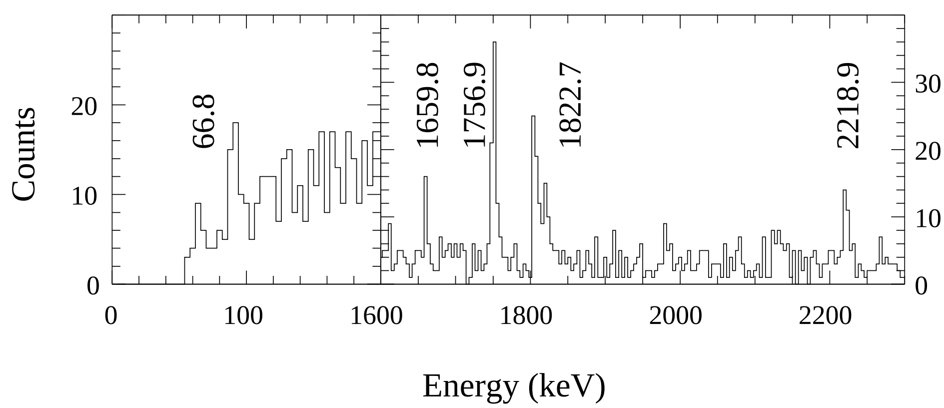

FIG. 1. γ spectrum in coincidence with high energy protons (x-axis in keV).

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[2] L.K. Fifield *et al.*, Nucl. Phys. **A437**, 141 (1985).

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Physics with Heavy Neutron−Rich RIBs at the HRIBF*

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We have performed an experiment using neutron−rich radioactive ion beams from the HRIBF facility, together with the CLARION Ge detector array and the HyBall CsI charged−particle detector array. A foil−plus−multichannel−plate detector was also placed at the achromatic focus of the Recoil Mass Spectrometer [1] and used to detect recoiling reaction products.

A beam of ^{118}Ag ($T_{1/2}$ ~2 s for ^{118m}Ag, $T_{1/2}$ ~4 s for ^{118g}Ag) was produced by proton−induced fission of ^{238}U, and accelerated to 455 and 500 MeV in the tandem accelerator. These energies required the use of the second stripping foil in the high−energy beam tube, but beam intensities on target of approximately10^6 ^{118}Ag ions per second were obtained. The data collected consisted of γ−HyBall coincidences, together with γ−γ−recoil coincidences where the recoil was detected in the multichannel−plate detector. The overall efficiency for detecting such products was about 40%.

Two different reactions were used. Firstly, a target of 0.6 mg/cm^2 ^{12}C was bombarded at 500 MeV. Fusion−evaporation reactions leading to the known nuclides ^{125,126}I [1] (5n and 4n evaporation) and ^{126}Te (p3n) were observed, together with α3n evaporation to previously unobserved states in ^{123}Sb. Also observed were inelastic scattering events, where a scattered ^{12}C from the target was detected with HyBall in coincidence with a γ ray detected in CLARION. Inelastic excitation of the first 2^+ state of ^{118}Sn, from a weak (approx. 5%) isobaric contamination of the beam can be clearly identified in the carbon−gated spectrum, suggesting an excellent means of performing Coulomb−excitation B(E2) measurements of RIBs in future experiments. In the γ−γ−recoil events, levels up to the known [2] $31/2^-$ state of ^{125}I were observed.

Secondly, a target of 1.25 mg/cm^2 ^{9}Be was bombarded at a beam energy of 455 MeV in an attempt to observe new levels in the 4n−evaporation product, ^{123}Sb. The γ−γ spectrum observed in coincidence with recoils was virtually identical to the α−gated γ−ray spectrum from the C target, confirming the assignment of the peaks to ^{123}Sb. With the Be target, a large number of α particles from incomplete fusion were also observed in the HyBall array.

Results from this test experiment, and plans for future measurements with Sn and Te neutron−rich radioactive beams, will be presented.

[1] C.J. Gross *et al.,* Nuclear Instrum. and Methods, **A450** (2000) 12.
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Triaxiality in Neutron Deficient Odd-Ta Nuclei?

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The high-spin $h_{11/2}$ and $i_{13/2}$ orbitals in odd-proton nuclei are convenient objects for studying the effects of nuclear shape changes. For such intruder orbitals there is less ambiguity about the nature of the wave functions than in the case of other orbitals.

Deviation from axial symmetry is generally expected for high-spin states. Although the signature splitting of the excitation energies offers a clue for possible γ - deformation, it appears even in the presence of only β - deformation. Therefore, in order to gain insight into the shape of the nucleus, the electromagnetic transition strengths must be investigated.

We report on odd- A neutron deficient Ta isotopes. Recently, data on ^{165}Ta [1], the most neutron deficient Ta isotope became available. Although data on some other Ta nuclei have already been analyzed by using the cranking shell model or projected shell model, no attempt has been made to obtain a systematic trend from the experimental data. For $^{165\text{-}179}$Ta isotopes, the shape favored by neutrons differs from the one preferred by the protons. One might therefore expect shape coexisting states and nuclear potentials that are very soft in the γ - degree of freedom. This was indeed obtained in the total routhian surface calculations [2].

The properties of the negative-parity $[514]9/2$ bands of $^{165\text{-}179}$Ta are used to study the relation between the signature splitting of the energies and the signature dependence of the $M1$ transition elements in connection with the deviation of nuclear shape from axial symmetry. The rapid increase of signature splitting with decreasing neutron number in the bands associated with the same quasiproton configuration strongly suggests that the observed trend is due to the properties of the even-even core and will reflect the nuclear shape. According to the cranking shell model calculations even a 50% change in the pairing gap barely affects the signature splitting. Also a variation of quadrupole deformation β_2 within the interval $0.16-0.29$ leads to small, almost constant signature splitting of the $\pi h_{11/2}$ orbitals. It seems that for the light odd-mass Ta isotopes only non-axially symmetric shapes can cause such an effect.

The analysis of the available experimental data on Ta isotopes indicates that lighter Ta nuclei exhibit an appreciable amount of deviation from axially symmetric shape (up to $\gamma = -18^o$ for ^{165}Ta).

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^{6}He+^{64}Zn around the Coulomb barrier

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Effects on the fusion cross-section are predicted by theoretical models in reaction induced by halo nuclei below and around the Coulomb barrier [e.g. 1]. Different models disagree about the role played by the break-up of the loosely bound halo nucleon. The reaction studied experimentally so far are not yet sufficient to clarify this physics[2-4]. No data for fusion evaporation reactions induced by halo nuclei on medium mass targets below the barrier are available so far owing to the low beam current, small cross-section and low evaporation residue (E.R.) energies. Moreover indirect E.R. detection, via on-line or off-line gamma spectroscopy, would also be very difficult due to the combination of low E.R. yield with low detector efficiency.
The reaction ^{6}He+^{64}Zn was investigated in order to study the effect of the ^{6}He structure on the fusion cross section around the Coulomb barrier. An excitation function for fusion reaction was performed by using the activation thecnique. The E.R. produced by fusion decay by Electron Capture (E.C.) so they are detected and identified by measuring the X-ray emitted after E.C. decay using a Si-Li detector. The clear advantage of the off-line X-ray technique is the 100% intrinsic detection efficiency and the low background for X-ray detection. We clearly identified five E.R. previously predicted by statistical model calculations (^{68}Ge, ^{66,67,68}Ga and ^{65}Zn) with half-lifes ranging from 1 hour to 300 days. Different isotopes of the same element which cannot be distinguished by atomic X-ray spectroscopy can be identified following the activity curve as a function of time. An activation run using a ^{4}He beam was performed in order to check the absolute normalisation by comparing our results with previously measured excitation function for ^{4}He+^{64}Zn using radiochemical method [5]. Along with the fusion excitation function, elastic scattering and transfer reactions were measured. The contribution of the transfer channel has been clearly identified for the first time in such kind of studies.

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Analysis of the ^{6}He(p,p'), ^{10,11}C(p,p') and ^{6}He(^{12}C,^{12}C) data at 40 A.MeV

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We have studied angular distributions of cross sections of elastic scattering of light exotic nuclei on targets of protons and carbon. Our aim was to know whether the weak binding of exotic nuclei should appreciably enhance the polarization potential, which includes the couplings to the continuum and break-up effects. We have also wanted to determine whether the models and the effective NN interactions, proved to be well adapted to the stable nuclei, had to be put into question when going far from the valley of stability.
Data for ^{6}He, ^{10,11}Be at 40 A.MeV on p and ^{12}C were measured at GANIL where the SISSI (Superconducting Intense Source for Secondary Ions) and the SPEG (Energy Loss Spectrometer at GANIL) devices have performed the production of the secondary beams and the detection of the scattered particles, respectively. The nucleus-nucleon interaction for the elastic scattering on protons is calculated with the microscopic, complex and parameter-free JLM potential [1]. A complex surface potential, with a repulsive real part, is expected to simulate the surface effects generated by the polarization potential [2]. By taking it into account, we have reproduced successfully a large set of data for the elastic scattering of exotic nuclei on protons at energies from 25 to 100 A.MeV.
In the case of ^{6}He $+^{12}$C elastic scattering, the energy resolution was good enough to separate the elastic scattering from inelastic contributions. The real part of the potential of interaction between the exotic nucleus and ^{12}C was calculated in the framework of the folding model, including new density-dependent NN interactions, recently obtained by D. Khoa and W. Von Oertzen [3]. With the polarization potential, the agreement found with the data is satisfactory.

For (p,p') reactions, the MUST device, a set of Si and Sili telescopes specifically designed to detect recoiling light charged particles, is used to measure angular distributions for elastic and inelastic scattering of radioactive beams on proton. (p,p') scattering data to the first excited state of ^{6}He at 1.8 MeV have been measured over a wide angular range with a 40.9A.MeV ^{6}He beam produced at Ganil. Inelastic scattering on proton, to the first excited state, for ^{10,11}C, were also measured at E_{lab} $\simeq$40 A MeV. The JLM potential is used to calculate the inelastic cross sections. The calculated inelastic (p,p') cross sections are sensitive to M_n/M_p factor, which is the ratio of the radial moments of the transition densities, $M_{p,n} = \int drr^{l+2}\rho^{tr}_{p,n}$. The extraction of nuclear structure information in terms of the M_n/M_p factor from the angular distributions of cross sections will be explained. We show that the ^{6}He(p,p') analysis is in favour with the halo configuration for this nucleus. The analysis of the ^{10,11}C(p,p') data is consistent with an extended matter radii of these nuclei, and with the alpha clusterization suggested in [4].

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Transfer Reactions with Radioactive Ion Beams at HRIBF *

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It is well-known that the order of single-particle orbitals changes as a function of neutron and proton number. In addition, the presence of deformation fragments the single-particle strengths. It is, therefore, critical to study single-particle transfer reactions on nuclei away from the valley of stability to probe the ordering of single-particle energy levels, single-particle spectroscopic factors, and the fragmentation of these strengths as a probe of deformation.

For nuclei away from the valley of stability such transfer reaction studies can only be performed in inverse kinematics, with a beam of the radioactive species hitting a hydrogenic target, for example. Such studies have been successfully performed at the ATLAS facility at Argonne, where a radioactive ^{56}Ni beam impinged on a thin CD_2 target with the mass/charge of energy-degraded beam-like residues selected by the Fragment Mass Analyzer and reaction protons from the (d,p) reaction were detected in a large, annular Si detector array at back angles in the target chamber. [1]

Two experiments have been approved to study transfer reactions in inverse kinematics using beams of ^{56}Ni and ^{92,94}Sr from HRIBF in which the heavy residues would be analyzed with the Recoil Mass Separator and light residues would be detected with position-sensitive Si detectors in the target chamber of the RMS. The present talk would discuss the experimental challenges as well as the prospects for transfer reactions with radioactive ion beams at HRIBF and in the future at RIA.

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Angular momentum transfer in fragmentation reaction

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Spin oriented ensemble and angular momentum transferred to a nucleus produced by fragmentation reaction process at intermediate energies are good tools to investigate such a process. Spin-aligned and spin-polarised nuclei coming from fragmentation reactions have been studied by several group [1-3]. At relativistic energies, it has been observed that the spin-alignment is related to the linear momentum distribution of outgoing fragments [4]. It was then deduced that the angular momentum transfer, spin-alignment and spin-polarisation are directly linked to the reaction mechanism involved.

Experiments performed recently using the LISE3 spectrometer from GANIL facility have investigated the fragmentation reaction mechanism at intermediate energies. The study of the angular momentum transfer occurred during this process have been performed by looking at the population of well known short-lived isomeric states close as well as far from the projectile. The spin-alignment and spin-polarisation of outgoing fragments have been also studied by using the β-LMR and β-NMR experimental techniques [5]. For the first time, a spin-polarised secondary beam have been produced at GANIL.

Experimental results have been quantitatively reproduced in the framework of kinematical [6] and statistical [7] models of nuclear reactions. The predictive power of models shows the possibility to produce isomeric useful for the study of reaction mechanism involved by isomeric beam, spin-aligned and spin-polarised secondary beams by fragmentation reaction useful for nuclear moment measurements.

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High Energy-Resolution Measures of Cross-Sections at RIBs *on the "Method of Spectra Superposition"* - MSS

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In order to estimate the highest possible energy resolution in excitation function-EF (beam-energy dependent cross-sections) , evolution of the initial beam-particle energy spectrum and distortion of the product-particle energy spectrum both are considered as functions of corresponding basic factors involved step by step in the low-energy elastic scattering just as an example.

The EF-energy-resolution independence on the beam (!) and contribution in the EF-distortion only of factors on the product-particle trajectory both are clearly shown.

During some last years the MSS was proven and successfully used in a number of experiments on low energy nuclear physics [1-4].

High significance and importance of the MSS-approach, as of a background for a large set of new energy-precise experiments especially at the Radioactive and Heavy-ion beams, is stressed promising reach results carried with a lot of new information.

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Confirmations of the New Observed Phenomena of the *"COMBINATIV ISOBAR RESONANCES"* - CIRs

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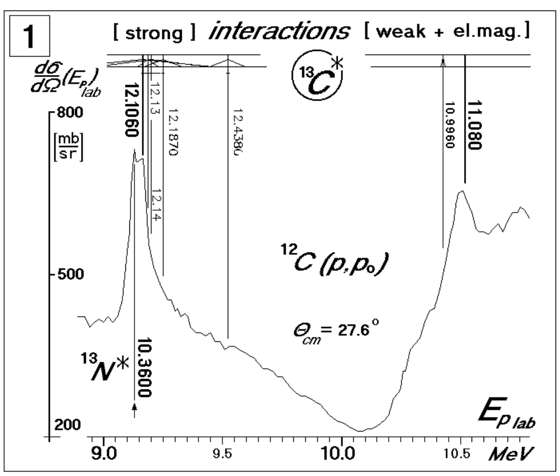
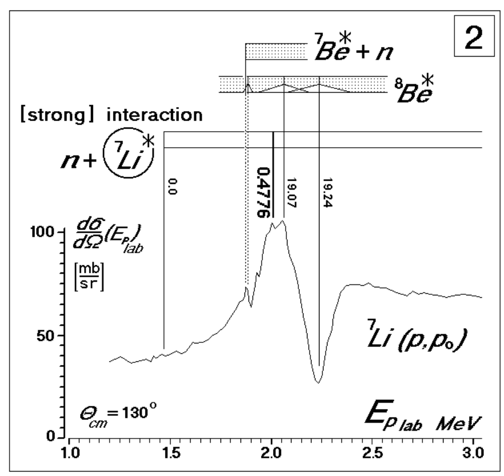
Many years, in the Nuclear Reaction Physics are known Resonances in the *Target-projectile*-system (RTPS) and fluctuations in cross-sections. What are they for certain? Very likely, answer to this can now become the most way to review all content of the Fusion Cycles...
Recently in high energy-resolution measures of Excitation Functions (EFs) at cyclotron using MSS-approach was obtained [1,2] the cross-section curve with 14 well known and large number of the RTPS which were identified only in suggestion that before the final nuclei&particles it take place formation of the isobaric charge-forbidden nuclei with the charge-equilibrium particle(s) inside [2,3]. These phenomena, enlarging number of the energy-accessible combinations of final products, display in $d\sigma(E)/d\Omega$ the respective additional anomalies named CIRs, arising due to the little known projectile-stimulated **soft** π [4,5]. CIR validity is confirmed [3] by the peaks found in [6,7] another EFs (see 1, 2 – lines of the forbidden nuclei $^{13}C^{\star}$ (12.106 MeV and 11.080 MeV) and $^{7}Li^{\star}$ (0.4776 MeV) through the CIR).





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Low Energy Fission of Heavy Exotic Nuclei *

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Results of investigation of shell effects in heavy ion induced low energy fission of transitional, Ac-Th, and super heavy compound nuclei will be discussed. Mass, energy distributions of fission fragments, pre- and post-fission neutron and gamma ray multiplicities from fission fragments will be presented.

Performed analysis of the experimental data for ^{226}Th with the use of a new multicomponent method [1] has shown that alongside the well-known modes, i.e., the symmetric (S) and two asymmetric modes standard-one (S1) and standard-two (S2) [2], a high-energy mode standard-three has manifested itself (S3). The last named mode appears due to the influence of the close-to-sphere neutron shell with N≈50 in the light fission fragment group [3].

In detailed measurements of mean gamma-ray multiplicities from fission fragments of ^{226}Th two components in M_γ(M) distribution were established. They were associated with different conditions during formation of fission fragments and it was shown that M_γ is very sensitive to symmetric and asymmetric modes and proprieties of the scission point. Theoretical calculations of the pre-scission shapes of the fissioning nuclei ^{224,226}Th confirm our conclusions.

Future experiments with exotic beams on study of shell effects in low energy fission with will be discussed.

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Systematics on cross sections from fragmentation and fission reactions

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Three reaction mechanisms provide the most promising prospects for the production of secondary beams. Fusion is best suited for the production of nuclei near the proton drip line. Fission specifically populates mid-mass neutron-rich isotopes. Fragmentation and spallation reactions represent rather universal production mechanisms for both neutron-deficient and neutron-rich exotic nuclei, since the fluctuations in the N-over-Z ratio are very important. Due to these large fluctuations, this is the most promising reaction mechanism to reach extremely exotic nuclei over the whole mass range, if sufficiently high primary-beam intensities are available. In particular, it seems to be a unique process for the production of extremely neutron-rich isotopes of elements above the region of fission fragments.

Computer models for understanding reaction mechanisms and predicting the cross sections of fragmentation and fission processes have been developed in our group [e.g. 1,3]. A great amount of experimental data on the production of residual nuclei in reactions at relativistic energies has been obtained in several experiments recently performed at GSI in inverse kinematics [e.g. 2-7]. On the basis of these data, realistic parameters for model calculations can be deduced, and the model predictions can be verified.

The good actual knowledge of the characteristics of the nuclear reactions allows for choosing conditions optimised to specific needs for the secondary-beam production. Using our experimental data and models it is possible to give rather realistic estimates on the prospects for secondary-beam production in next-generation facilities.

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Investigation of t+t collisions using ACCULINNA beam line and a liquid tritium target

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The use of a tritium target in experiments with radioactive beams seems to be promising for the study of light neutron-drip nuclei. In this respect, favorable are transfer reactions between tritium nuclei and neutron-excess projectiles studied in a projectile energy range of 15–30 MeV/n. Relevant examples could be 2n-transfer reactions $^3H+^3H \to ^5H+p$, $^8He+^3H \to ^{10}He+p$, etc., or 1p-transfers $^8He+^3H \to ^7H+\alpha$, $^{11}Li+^3H \to ^{10}He+\alpha$, etc. Angular distributions obtained for reaction products in these reactions can give useful information about clustering structures in both the exotic projectiles and drip-line reaction products [1,2]. However, the use of a tritium target is even more promising for the study of resonance states of nuclei lying beyond the neutron drip line. Recently, an environmentally safe liquid-tritium target was installed at the radioactive beam line of separator ACCULINNA [3] working with primary beams of U-400M cyclotron. The target cell has a material thickness of 0.4 mm for tritium, beam opening of a diameter of 10 mm and the entrance and exit windows closed with two pairs of 12-μ stainless steel foils. On both sides, these foils are vacuum-tight welded to the cell body providing two small vacuum volumes equipped with a tritium absorber, which prevents the penetration of tritium leaks in the reaction chamber.

Separator ACCULINNA was upgraded to meet conditions imposed by the tritium target and improve precision for the transfer reaction study. The beam line was extended in order to deliver the beam beyond the cyclotron hall to a low-background room where a reaction chamber housing the target and position sensitive $\Delta E \times E$ Si-telescopes is installed. Neutron wall based on 41 DEMON detectors was placed at a distance of 2.5 m from a target.

A primary beam of 58 MeV tritons was obtained from the U-400M cyclotron and delivered to the tritium target. The separator ion optics was used to select the beam having widths of >0.5 % and $>0.5^\circ$ in the energy and angular distributions. Being delivered to the tritium target the triton beam with an intensity of 1×10^8 s^{-1} was focused in a 4-mm spot. All together, the beam quality, target parameters and performance of detector telescopes, allow one to have a resolution of >300 keV for the widths of ^5H resonance states, which could result from the t+t reaction. One resonance state around 1.9 MeV was recently obtained for this nucleus in reaction $^6He+p \to ^5H+2p$ [4]. Results of an experiment aimed at the study of transfer reactions occurring in t+t collisions will be presented.

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The Cross-Sections of the Photonuclear Reactions

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The cross-sections of the photonuclear reactions (γ,γ'), (γ,n) and (γ,2n) measured for the 92 nuclear in the region between ^{12}C and ^{238}U. The measurements were performed by the activation method on the bremsstrahlung of the microtron with the boundary energy of 13 and 22Mev.The cross-sections were calculated using the modificated model of the preequilibrium decay. The satisfactory agreement of the experimental and calculated cross-section was observed.

Breakup of Weakly Bound ^{17}F by ^{208}Pb at 170 MeV Bombarding Energy *

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It has been demonstrated that the coupling of nuclear reaction and nuclear structure degrees of freedom of fusing nuclei leads to the enhancement of subbarrier fusion cross section. The advent of radioactive beams stimulates studies of subbarrier fusion with weakly bound nuclei. The large r.m.s. radius associated with these nuclei and the excitation to the soft dipole resonance could reduce the barrier for fusion. However, the influence of the breakup of weakly bound nuclei on subbarrier fusion is still an open question. We have measured the breakup of 170 MeV ^{17}F bombarding a ^{208}Pb target. The breakup fragments were identified by a double sided strip detector and Si surface barrier detector ΔE-E telescope. The angular distribution of the ^{16}O fragments was found to disagree with the dynamical calculation and the coupled discretized-continuum channels (CDCC) calculation. The CDCC calculations underpredict the energy spectra of ^{16}O by a factor of 8. Further experiments at energies closer to the Coulomb barrier for investigating the influence of breakup on fusion and the discrepancy between measurement and calculation will be discussed.

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Advances in ISOL technology at IGISOL

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The IGISOL facility [1] at the Department of Physics of the University of Jyväskylä (JYFL) is delivering radioactive beams of short-lived exotic nuclei, in particular the neutron-rich isotopes from fission reaction. These nuclei are studied with the nuclear and collinear laser spectroscopy methods. In order to obtain a meaningful increase, in comparison to a standard level, of precision and sensitivity of such studies an improvement of the radioactive beam quality is necessary. This improvement will be achieved due to a radioactive beam handling which consists of three steps: beam cooling, bunching and (isobaric) purification. The latter means a possibility of obtaining a pure monoisotopic beam. Beam handling may be done with an aid of ion traps, in particular of RF and Penning type.

Cooling and bunching are performed with the use of an RFQ cooler/buncher [2]. It is essentially a classical RFQ mass filter filled in with a buffer gas (usually helium). There, an oscillating RF-field is confining the beam axially. At the same time, beam particles are thermalized by collisions with buffer gas. An outcome of this process is a substantial decrease of both transverse emittance and energy spread. The RFQ cooler/buncher was built at JYFL and works well several months already. First successful applications were on the collinear laser spectroscopy where large enhancement on sensitivity was achieved.

The isobaric purification will be made by a Penning trap [3] placed after the RF-cooler. It uses mass-selective buffer gas cooling technique. The latter needs creating a radiofrequency quadrupole field and presence of the buffer gas. The RF-frequency is chosen so that it is equal to the cyclotron frequency of the ions of interest, which are usually mixed with other, contaminating ions. The joint action of the RF-field and the buffer gas is cooling and centering the ions of interest on the trap axis, whereas contaminants are not centered. The ions of interest are then ejected through a small hole in the endcap of the trap. This process can have a high mass resolving power, of the order of 10^5, which permits to reject even isobaric contaminants. This trap is being assembled and tested now. Major part of related equipment, including B=7 T superconducting magnet, exists already.

This contribution describes the current status of the ion trap upgrade of the IGISOL facility and its future prospects. The latter comprise, apart from the experiments mentioned above, also precise nuclear mass measurements and nuclear spectroscopy in the Penning trap interior.

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Negative Ion Beam Production by Sequential Charge Transfer in Tandem Mg and Cs Vapor Cells

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Ion beams produced at an ISOL facility are usually positively charged. However the HRIBF at Oak Ridge National Laboratory requires negative radioactive ion beams for injection in the tandem accelerator. A general way applicable to many elements is to change the positive ion beam into a negative ion beam by charge exchange in a suitably chosen gaseous medium. In this case, the charge exchange is a two step process where the electron transfers first produce neutral atoms and then negative ions. An experimental challenge in this connection is to produce a negative ion beam with a small emittance by optimizing the selection and the thickness of the charge exchange medium. For the example of producing a low emittance negative As beam, experiments were carried out at UNISOR with either Mg or Cs vapors as the charge exchange medium. The corresponding charge exchange rates were measured for different As beam energies and the resulting beam divergences were estimated via the intensity decrease of the transmitted beams. While both vapor targets produced negative ions, Mg was shown to be an excellent medium for making the first step namely neutral beams, and Cs for making the second step namely negative ion beams from neutral beams. This is due to their difference in ionization potentials and electron affinities. The results of the measurements suggested the application of two charge exchange cells placed one after the other, with Mg vapor in the first cell and Cs vapor in the second. This arrangement was implemented and the tandem arrangement resulted in the minimum target beam divergence for producing negative As beams. Experimental results and rate equations describing the two step charge exchange processes are discussed. The experiment demonstrated the advantage of properly choosing projectile-target combinations with minimum energy defects .

The beam diagnostics systems of the EXCYT facility at LNS

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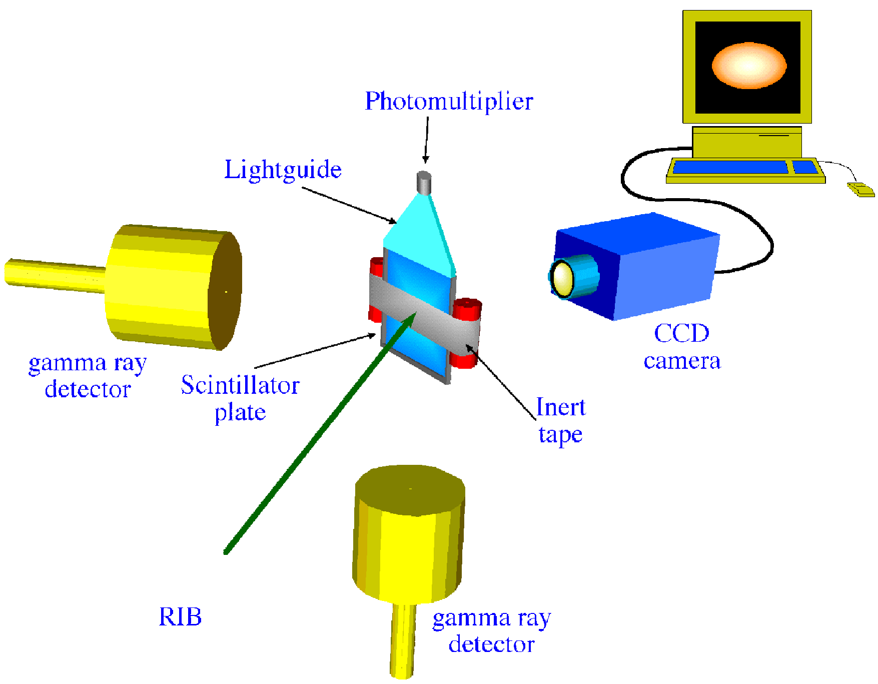
EXCYT (EXotics with CYclotron and Tandem) is the ISOL facility under development at INFN - LNS Catania (Italy) [1], for the production of radioactive beams with energies ranging from 0.2 up to 8MeV/A, emittance less than 1π mm·mrad and energy spread less than 10^{-4}. The primary beam (E $\leq$ 80MeV/A, A<48) is accelerated by the superconducting cyclotron (CS) and transported onto a graphite thick target, from which the radioactive ions of interest are extracted and then selected by a high resolution magnetic isobar separator ($\Delta E/E$ = 1/20000), which rejects the isobaric contaminants. After the separator the beam has a kinetic energy of 300keV and can be accelerated by the 15MV Tandem. The beam intensity is expected to be in the range from 10^3 pps up to 10^9 pps, depending on the intensity of the primary beam (< 1pμA), on the production cross section in the target and on the overall extraction efficiency from the source.

In order to have a suitable check of the beam properties (profile, intensity, ion composition, etc.) for the beam tuning requirements, the facility needs an efficient beam diagnostics. Taking into account the peculiarities of the beams, we have developed a series of diagnostics devices based on particle detectors, like scintillators, semiconductors and gas chambers [2]. The device for the beam imaging is based on a CsI(Tl) scintillator plate and exploits the radioactive decay (mainly β and γ) of the ions, in order to produce a light spot which represents the transversal profile of the beam. In the same device a couple of germanium detectors should recognize the nuclides present in the beam, by acquiring their energy gamma spectrum. Concerning the beam pipe after the tandem accelerator, devices based on a high resolution silicon telescope that can revolve around a target, will be installed. They are able to identify the beam nuclear species by means of scatter plots.



Sketch of the device for beam imaging and identification.

[1] G. Ciavola et al., Nuclear Physics A616 (1997) 69c-76c.
[2] P. Finocchiaro, CAARI 98, 15th Internat. Conf. on the Appl. of Accel. In Research and Industry, Univ. of North Texas Denton, November 4-7, 1998.

Acceleration of Radioactive Ions with REX-ISOLDE

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The ISOLDE facility placed at CERN, Geneva has been successfully used for the production of radioactive ions since more than 30 years. Until now the beam energy available is at 60 keV. The aim of REX - ISOLDE (Radioactive beam EXperiment at ISOLDE) is to overcome this and to post - accelerate light ($A \leq 50$) radioactive ions up to an energy of 0.8 - 2.2 MeV/u. At this energy coulomb excitation and particle transfer reactions can be used to study nuclear structure far of stability. For many cases this will be done via γ -spectroscopy with the MINIBALL, a 4π Ge detector array. First experiments plan to investigate neutron rich isotopes near to the magic neutron numbers 20 and 28. Beside this, measurements in astrophysics, atomic physics and solid state physics are planed. They will make use either of the availability of having highly charged radioactive ions or the high and variable energy of them.

The setup is shown in figure 1. A unique system for beam preparation is used. It consists of a Penning trap for beam accumulation and bunching and an electron beam ion source (EBIS) for charge breeding, which can deliver a very clean beam of bunches of highly charged radioactive ions. An additional advantage is the fast breeding time to reach an A/q value of about 4.5, which is necessary for the accelerating structures. For isotopes below A=50 the required charge state can be reached within less than 20 ms. This enables it to handle also short-lived isotopes. After a mass separator to choose the right A/q value a linear accelerator formed by an RFQ, an IH structure and three 7-gap resonators is used to accelerate the ions. Finally there are two target and detector stations, one for the installation of the MINIBALL and one for other experiments.

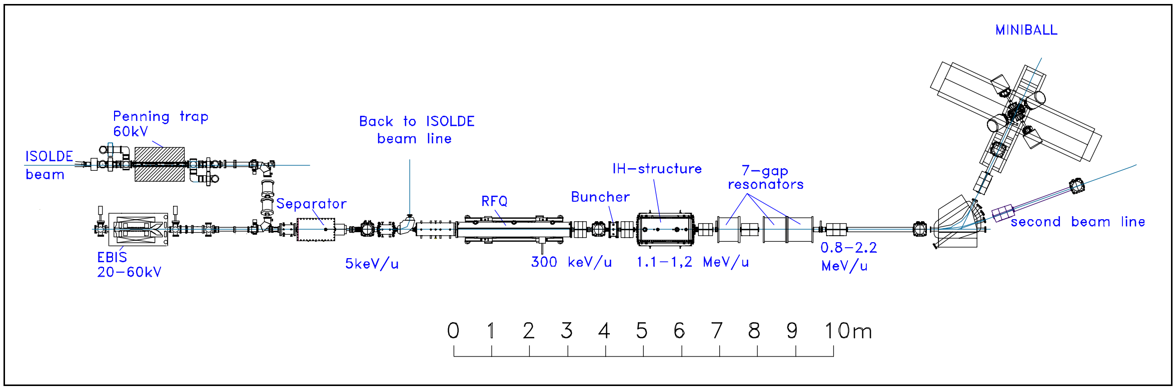

FIG. 1. Top view of the REX-ISOLDE post accelerator.

All components of the set-up are finished, tested and most of them are already installed at the ISOLDE facility. The accumulation, cooling and bunching of ions delivered by ISOLDE, has been demonstrated with the Penning trap. Acceleration up to 300 keV/u of ion bunches delivered by the EBIS with the RFQ has been successfully carried out. The status of the commissioning of the whole installation, especially the interplay of the different components will be presented.

The Radioactive Ion Beam Accelerator MAFF at the Munich High Flux Reactor FRM-II

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At the Munich high flux reactor FRM-II the Munich accelerator for fission fragments (MAFF) is under design [1,2] in order to produce intense beams of very neutron-rich fission fragments of up to 10^{12} particles/s. Thermal neutron induced nuclear fission is the most suitable method to produce neutron-rich isotopes (70<A<160) due to the large fission cross section and the high thermal neutron fluxes in modern reactors. The beams at MAFF will be delivered to experiments at low energy (30 keV) as well as at high energies between 3.7 and 5.9 MeV/u. The neutron rich isotopes are of interest in many different fields of nuclear physics, astrophysics, solid state physics and medicine. One of the key experiments will be the production and the study of the nuclear and atomic properties of very heavy elements with Z>100. An overview of the production method of neutron rich isotopes by thermal neutron induced fission, of the machine layout and of the experiments will be shown.

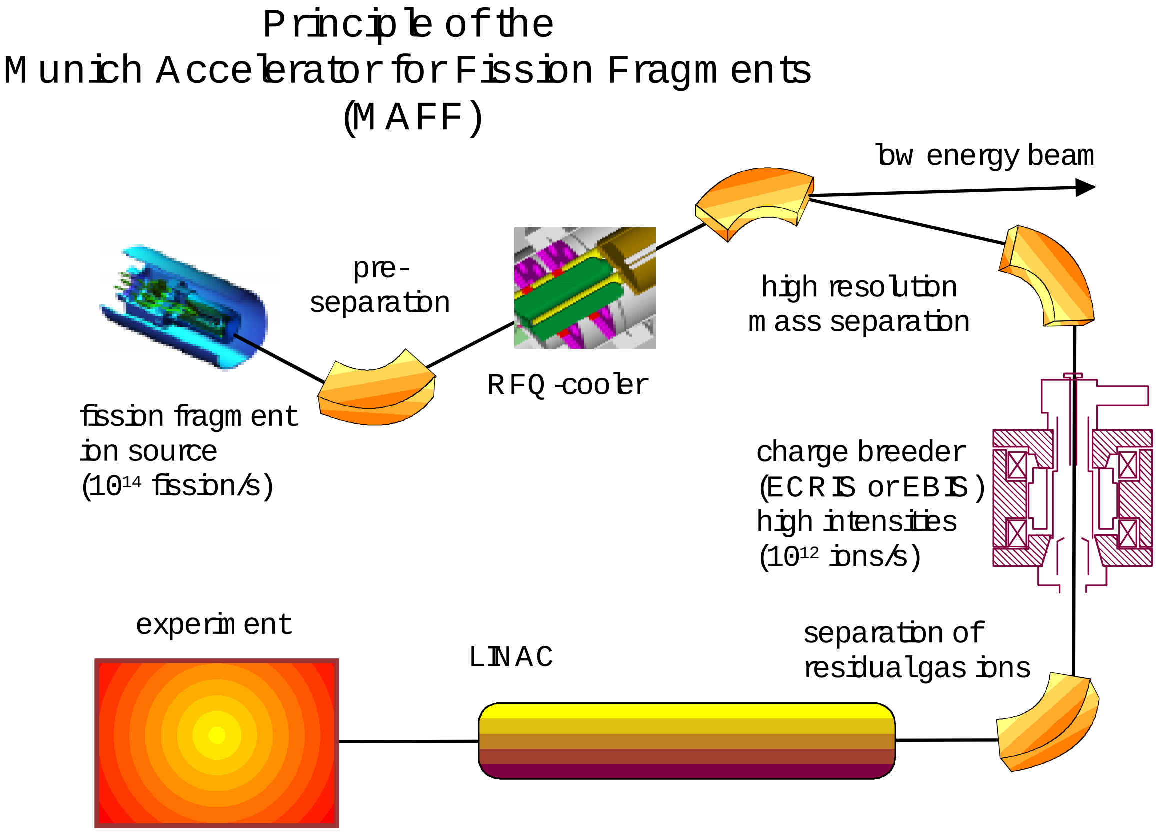

FIG. 1. Schematic of the MAFF layout.

[1] O. Kester et al., Nucl. Instr. and Meth. B 139 (1998) 28-36
[2] MAFF - Physics Case and Technical Description,
(http://www.ha.physik.uni-muenchen.de/maff/)

Nuclear reaction modeling for RIA ISOL target design

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Los Alamos scientists are collaborating with researchers at Argonne and Oak Ridge on the development of improved nuclear reaction physics for modeling radionuclide production in ISOL targets. This is being done in the context of the MCNPX simulation code, which is a merger of MCNP and the LAHET intranuclear cascade code, and simulates both nuclear reaction cross sections and radiation transport in the target. The CINDER code is also used to calculate the time-dependent nuclear decays for estimating induced radioactivities. We will give an overview of the reaction physics improvements we are addressing, including intranuclear cascade (INC) physics, where recent high-quality inverse-kinematics residue data from GSI have led to INC spallation and fission model improvements; and preequilibrium reactions important in modeling (p, xn) and $(p, xnyp)$ cross sections for the production of nuclides far from stability.

Rare Beam Production below the Fermi Energy at Texas A&M. *

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The possibility of rare isotope production around and below the Fermi energy regime is investigated using the MARS recoil separator at TAMU. The reaction of 20 MeV/nucleon ^{78}Kr on ^{27}Al is employed for the production of proton rich nuclides (especially N=Z). For neutron rich nuclides, the reaction of 20 MeV/nucleon ^{86}Kr on ^{64}Ni is utilized. In addition, the fission of ^{238}U projectiles at 10 MeV/nucleon following interaction with a ^{64}Ni target is explored as a source of extremely neutron-rich nuclei. The experimental results on rates of rare isotopes will be presented and compared to results of reaction simulations. Apart from in-flight possibilities, the option of utilizing such reactions (in normal or inverse kinematics) at these or lower energies for rare isotope production in ISOL-based facilities will be discussed. Finally, possible application of such reactions in current plans of ISOL-type rare beam production at TAMU will be mentioned.

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Photofission for the SPIRAL II Project

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Abstract :

The SPIRAL II project at GANIL is aiming at a significant enhancement in the production of some exotic ion over the current state of the art. One very attractive option is the use of a rather compact electron accelerator, taking benefit of the giant dipolar resonance in uranium through photofission. In this paper, a possible layout for the driver accelerator and a preliminary design of the target is sketched. Target calculations including Bremsstrahlung photon spectra and nuclear reactions are presented giving the expected number of fission per second and the corresponding neutron flux. Hence, the estimated exotic beam in-target production is deduced for some typical radioactive neutron rich ions.

RADIOACTIVE ION BEAMS PRODUCTION WITH PHOTOFISSION OF URANIUM ISOTOPES.

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(Samarkand state University, Uzbekistan)

The use of a radioactive beam of ions with neutron excess higher than in the stable ^{48}Ca nucleus could solve the problem. Reactions of cold fusion between massive nuclei with masses and charges close to those of fission fragments may turn to be promising for these purposes.

To make the picture complete, note that it is possible to use extremely expensive, but very convenient photofissions on ^{238}U and ^{235}U.

The yield photofissions ^{238}U and ^{235}U fragments was determined experimentally at a beam of electrons produced by the compact accelerator of the microtron type MT-22S.

The facility MT-22S produces a beam of electrons with an energy E_e=13-22 Mev and intensity of 20 μA. A W plate 2 mm in thickness was used a convertor.

A standard “sandwich” consisting of then U_2O_3 layer deposited on an Al (20μm) backing and a plastic track detector (Mylar-50 μm) was used for the fission fragment registration. Pb plates of various thick nesses imitating the solid U-target were placed in between the “detector sandwiches”.

It is shown that in the interaction between an electron beam (22 Mev and 20μA in intensity) and uranium target of about 40 g/cm^2 in thickness, an average of $1{,}3 \cdot 10^{10}$ fission events/second is generated.

According to the calculations and test experiments, this corresponds to the yield of ^{132}Sn and ^{142}Xe isotopes of approximately-10^8/s.

The photofission reactions of a heavy nucleus are compared with other methods of radioactive beams production of medium mass nucleus.

Ion source development of the on-line isotope separator at JAERI*

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The JAERI on-line isotope separator (JAERI-ISOL) [1] at Japan Atomic Energy Research Institute, Tokai, is utilized to search for new isotopes and to investigate spectroscopic studies for nuclei far from stability. So far, two type of ion sources have been developed – a cavity type thermal ion source and a gas-jet coupled thermal ion source [2]. Both sources can give high ionization efficiencies for lanthanide and actinide atoms. With the previously established ion-source technique using mono-oxide ion formation in the thermal ion source [3], the new isotopes ^{121}La, ^{125,127}Pr were identified in heavy-ion fusion residues [4,5]. Further, with the gas-jet coupled thermal ion source, the new isotopes ^{159}Pm, ^{161}Sm, ^{165}Gd, ^{166,167,168}Tb produced in the proton-induced fission of ^{238}U have been identified [6].

Thereafter, to extend our investigation to the actinide region, the mass-separation of neutron-deficient americium and curium isotopes produced via ^{233,235}U(^{6}Li,*x*n), ^{237}Np(^{6}Li,*x*n) reactions was attempted. For effective transport of actinide atoms from the target chamber to the thermal ion source, we developed a gas-jet coupled multiple-target chamber. This chamber can be set about 20 target foils, thus, the effective target thickness of about 2 mg/cm^2 is achieved. Then, we successfully applied to the identification of the new isotope ^{236}Am produced in the ^{235}U(^{6}Li,5n) reaction [7].

To further the study of more neutron-deficient americium and curium isotopes, ^{233,234,235}Am, ^{237}Cm whose production cross sections are estimated to be 1-10 μb in ^{233,235}U(^{6}Li,*x*n) reactions and 1 μb in ^{237}Np(^{6}Li,6n) reaction, respectively, we needed the improvement of the overall efficiency and the stable operation of the ion source for long time without serious restrictions. The overall efficiency of 0.3-0.4% including ionization efficiency and transport one of the gas-jet system for americium atoms was achieved by using the He/PbI_2 aerosol jet system. A long operation of the whole system was examined in on-line experiment for the mass separation of ^{235}Am produced in the ^{235}U(^{6}Li,6n) reaction. The beam intensity of ^{235}Am was stable during the experiment. This indicates that the ion source can be stably operated for 100 h or more. The performance of the present system was demonstrated in an identification of the new americium isotope ^{233}Am [8].

This contribution describes the performance of the multiple-target He/PbI_2 aerosol jet system coupled with the thermal ion source used for the mass-separation of americium and curium isotopes produced in ^{233,235}U(^{6}Li,*x*n), ^{237}Np(^{6}Li,*x*n) reactions. The identification of the new neutron-deficient ^{233}Am [8] and ^{237}Cm isotopes with this system is also presented. In addition, the future plan using an integrated target-FEBIAD-type ion source and a surface ionization type one designed for mass separation of neutron-rich isotopes produced in the proton-induced fission of ^{238}U will be introduced.

[1] S. Ichikawa *et al*., Nucl. Instr. Meth. B **70**, 93(1992).
[2] S. Ichikawa *et al*., Nucl. Instr. Meth. A **374**, 330(1996).
[3] S. Ichikawa *et al*., Nucl. Instr. Meth. A **274**, 259(1989).
[4] T. Sekine *et al*., Z. Phys. A **331** ,105(1988).
[5] A.Osa *et al*., Nucl. Phys. A **588**, 185c(1995).
[6] M.Asai *et al*., Phys. Rev. C **59**,3060(1999).
[7] K.Tsukada *et al*., Phys. Rev. C **57**, 2057 (1998).
[8] M.Sakama *et al*., Eur. Phys. J. A **9**,303(2000).

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Rate Measurements of Radioactive Neutron Rich Beams Produced via Proton Induced Fission at HRIBF

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A systematic study of the rates of radioactive nuclei produced via fragmentation was performed at the Holifield Radioactive Ion Beam Facility (HRIBF). A Uranium Carbide target was bombarded with a 20 MeV proton beam with an intensity of 2 μA. Fission fragments were produced and separated by the ISOL technique, and then implanted on a moving tape and transported to a Ge detector. Rates of individual species from A=78 to 145 will be presented.

Ion Sources used in the Production of Radioactive Ion Beams at the HRIBF

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Radioactive ion beams are produced at the Holifield Radioactive Ion Beam Facility (HRIBF) using the ISOL technique where the atoms are produced in a thick target, transported to an ion source, ionized, and extracted from the ion source to form an ion beam. At the HRIBF, the radioactive ion beams thus produced are accelerated to 200 keV for injection into a tandem electrostatic accelerator, further accelerated up to a few MeV per nucleon, and then delivered to experimental stations for use in nuclear physics and astrophysics studies. The radioactive nuclei are produced via light ion (p, d, ^{3}He, α) induced reactions on the target nuclei. These production beams are provided by a K=100 cyclotron. To date, the production beam intensities have been limited to 12 μA by the ability of the production target to withstand the deposited power.

The types of ion sources used to produce radioactive ion beams vary considerably. Since negative ions are required for injection in the tandem accelerator, most of the ion source development effort has been focused on improving the efficiency and durability of sources that produce negative ions directly. Three such sources have been used at the HRIBF to produce radioactive ion beams, either on the RIB Injector Platform or during tests with low-intensity production beams at the UNISOR Facility. In some cases, where the electronegativity of the element is relatively low, it is more efficient to make positively charged ions and then create negative ions by passing the low-energy positive-ion beam through a charge exchange cell containing a metal vapor. At the HRIBF a cesium-vapor cell is used. The ion sources used at the HRIBF are listed below.

- Kinetic Ejection Negative Ion Source (KENIS) [1] – used to produce beams of ^{17,18}F from targets of aluminum oxide and hafnium oxide fibers.
- Electron Beam Plasma Ion Source (EBPIS) [2] – used to produce positive-ion beams of proton-rich isotopes of As, Ga, and Cu using liquid metal targets and F from fibrous oxide targets. Also used to make beams of many fission fragments produced in a uranium carbide target.
- Batch-mode Cs-sputter ion source [3] – used to produce beams of long-lived nuclei from solid targets.
- Negative Surface Ionization Source [4] – utilizes a LaB_6 surface to produce negative ions of bromine and iodine from a uranium carbide target.

The poster presentation will provide more information on each of these sources, including the unique capabilities of each and their usefulness to the HRIBF.

[1] G.D. Alton, Y. Liu, C. Williams, and S.N. Murray, *Nucl. Instr. and Meth.* **B 170**, 515-522 (2000).
[2] Carter, H.K., et al., *Nucl. Instr. Meth.* **B 126**, 166 (1997). (Lists of extracted beams and the measured intensites are available at www.phy.ornl.gov/hribf/users/beams/).
[3] G.D. Mills, G.D. Alton, D.L. Haynes, and J.R. Beene, *Physics Division Progress Rpt. ORNL-6957, Sept. 1998* (available at www.phy.ornl.gov/progress/hribf/randd/hri031.pdf).
[4] H. Zaim, Y. Liu, S.N. Murray, and G.D. Alton, to be published in *Application of Accelerators in Research and Industry*, edited by J. L. Duggan and I. L. Morgan, AIP Conference Proceedings, New York: American Institute of Physics, 2001.

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† Managed by Oak Ridge Associated Universities, for the U.S. Department of Energy under contract DE-AC05-00OR22750.

Negative Ion Beam Cooling Using a Collisional RF Quadrupole Ion Guide

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The Holifield Radioactive Ion Beam Facility (HRIBF) uses the Isotope Separator On-Line (ISOL) technique to provide accelerated radioactive ion beams (RIBs) for nuclear structure physics and nuclear astrophysics research. The radioactive ion beams produced are often mixed with isobaric contaminants that compromise experimental results. At the HRIBF, a magnetic mass separator with a nominal mass resolving power of M/ΔM ~20,000 is provided for isobaric purification. However, in order to achieve this high resolving power in practice, a very high quality beam (one with a very small emittance and energy spread) is required. The tandem accelerator at the HRIBF requires negatively charged ions as input. Negative-ion beams are most often generated in Cs-sputter sources or by means of charge conversion of positive-ion beams. In both cases, the resulting negative-ion beams have inherently large emittances due to the large energy spreads associated with the energetic sputtering or charge transfer processes. Thus, the degree of isobaric purification that otherwise could be obtained is limited by the rather poor qualities of negative beams from these sources.

We have investigated the feasibility of cooling negative ion beams by injecting them into a gas-filled RF quadrupole ion guide where their energies are dissipated in collisions with a buffer gas. After reaching thermal energy distributions with the buffer gas, the ions can be re-accelerated to form beams with the qualities required for effective mass resolution of contaminant and beams of interest. The objective of the present studies was to develop a system and evaluate its feasibility for cooling negative RIBs to achieve beam qualities required for eliminating contaminant isobars through magnetic analysis without sacrificing intensity. To this end, we have constructed an ion cooler, consisting of a deceleration stage, a gas-filled RF quadrupole, and a re-acceleration stage, and used it to cool negative-ion beams with initial energy distributions >10 eV to energy spreads ~2 eV with an overall transmission efficiency of ~17% for F^- beams. A detailed description of the collisional cooler and results derived from cooling experiments with both negative- and positive-ion beams will be presented.

* Managed by UT-Battelle, LLC, for the U.S. Department of Energy under contract DE-AC05-00OR22725.

A New Concept Kinetic-Ejection Negative-Ion Source for Rib Generation

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Chemically active radioactive species are often released from target materials in a variety of molecular forms. For example, ^{17}F is principally released from Al_2O_3 target material as $Al^{17}F$. Because of the low probability of simultaneously dissociating such molecular carriers and efficiently ionizing their atomic constituents with conventional hot-cathode, electron-impact ion sources, species of interest are often distributed in several mass channels in the form of molecular side-band beams. Consequently, beam intensities of the desired radioactive species are diluted. The sputter negative-ion beam-generation technique is particularly effective for simultaneously dissociating molecular carriers and efficiently ionizing highly electronegative atomic constituents. Therefore, a new concept kinetic-ejection negative-ion source (KENIS), based on this principle, was conceived to address this problem. The source has proven to be highly efficient for simultaneously dissociating and negatively ionizing sputter-ejected atomic fluorine from cesiated surfaces. The source has been successfully employed on-line to generate high-intensity $^{17}F^-$ beams for use in the astrophysics research program at the Holifield Radioactive Ion Beam Facility (HRIBF) using the $^{16}O(d,n)^{17}F$ reaction. The mechanical design features, principles of operation, operational parameters, beam quality information (emittance data) and efficiencies for forming intense beams of $^{17}F^-$ during off-line and on-line operation of the source are presented in this report.

[*] Managed by UT-Battelle, LLC, for the U.S. Department of Energy under contract DE-AC05-00OR22725.
[†] Managed by Oak Ridge Associated Universities for the U.S. Department of Energy under contract DE-AC05-00OR22750.

Selection of Refractory Target-Materials and Design of High Efficiency Diffusion-Release Targets for Radioactive Ion Beam Applications

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Many of the reactions fundamentally important in nuclear physics and nuclear-astrophysics are inaccessible to experimental study using stable-beam/stable-target combinations and therefore can only be studied with accelerated radioactive ion beams (RIBs). As a consequence of worldwide interest in these research opportunities, facilities have either been constructed or are under construction for the production and acceleration of RIBs. Several of the facilities utilize the Isotope-Separator-on-Line (ISOL) technique. Experimentally useful RIBs are often difficult to generate by this technique, since they must be diffused from the interior of the target material, effusively transported to the ionization chamber of the source, ionized, extracted, mass-analyzed, and accelerated to research energies in a time-span commensurate with their lifetimes. The speeds at which these processes must take place, impose stringent requirements on the choice of the most appropriate refractory-target-material; on the design of fast diffusion-release targets; on the fabrication and optimization of fast vapor transport systems; and on the choice of the most efficient ion source for RIB generation. In this report, we define criteria for choosing target materials and for designing mechanically stable, short diffusion-length, highly permeable targets, and how vapor pressure, equilibrium concentration, and limiting temperature properties are used to make their selection. We illustrate the viability of the target design philosophy by providing diffusion-release and vapor transport data for a selected number of radioactive species from small diffusion-length, highly-permeable targets that have been successfully used for the generation of RIBs at the Holifield Radioactive Ion Beam Facility (HRIBF).

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[1] Direct inquiries concerning this report to: gda@ornl.gov.

[2] Managed by UT-Battelle, LLC, for the U.S. Department of Energy under contract DE-AC05-00OR22725.

Negative Surface Ionization Source Equipped with a Spherical Geometry Lanthanum Hexaboride Ionizer for Production of Negative Halogens for RIB Generation†

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A versatile, efficient, simple surface ionization source has been designed, fabricated, and initially tested for on-line use in generating radioactive ion beams of members of the group VII A elements (F, Cl, Br, I, and At) for the Holifield Radioactive Ion Beam Facility research program. The source utilizes a solid, spherical geometry, low work function LaB_6 ionizer ($\phi \cong 2.3$ to 3.2 eV)[1] for ionizing highly electronegative atoms and molecules. Despite its widely publicized propensity for being easily poisoned [2], no evidences of this effect were experienced during testing of the source. Off-line evaluation in terms of ionization efficiency for generating beams of Br^- by feeding $AlBr_3$ vapor at low feed rates into the source proved that the source is reliable, stable and easy to operate. The results indicate nominal efficiencies of 15% for Br^- beam generation when taking into accounts the fractional thermal dissociation of the $AlBr_3$ carrier molecule. The design features of the source are illustrated in Figure 1. Principles of operation of the source, initial performance, operational parameter and beam quality data (emittance) are discussed in this report.

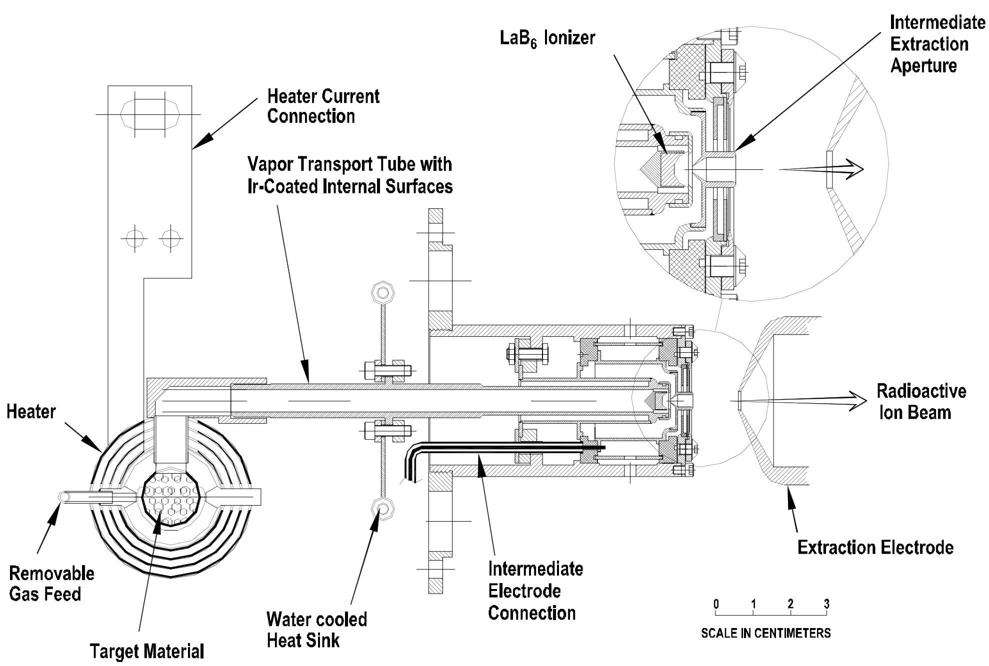

FIG. 1. Schematic drawing of the negative surface ionization source equipped with the spherical geometry LaB_6 ionizer.

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† Research sponsored by the U.S. Department of Energy under contract DE-AC05-00OR22725 with UT-Battelle, LLC.
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Effusive-flow of Pure Elemental Species in Tubular Transport Systems: Radioactive Ion Beam Applications*

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Maximum practically achievable intensities are required for research with accelerated radioactive ion beams (RIBs). The principal means whereby short-lived radioactive species are lost between their formation and their acceleration are time delays due to diffusion from solid or liquid target materials and effusive-flow transport time to the ion source. Then, these delay times must be minimized. We developed an analytical formula that can be used to calculate characteristic effusive-flow times through tubular transport systems, independent of species, tube material, and operational temperature for entirely ideal cases. This equation permits choice of materials of construction on a relative basis that minimize the transport times, independent of transport system geometry and size.

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Thermal Modeling of UC_2 and ZrO_2 Targets for 1 GeV Protons

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The intensity of radioactive ion beams (RIB) produced by the isotope separator on-line (ISOL) technique depends on the production rate and the efficiency with which the radioactive species can be transported out of the target and formed into an ion beam. In order to maximize production rates and minimize transport delay times, targets that operate at the highest practical temperatures and production-beam powers are desirable. High-efficiency-release targets that simultaneously incorporate fast and efficient diffusion release properties have been successfully developed for the generation of useful radioactive ion beam intensities for nuclear physics and nuclear astrophysics research at the Holifield Radioactive Ion Beam Facility (HRIBF). Short diffusion lengths are achieved either by using thin fibrous materials as targets or by coating thin layers of selected target material onto low-density carbon fibers such as reticulated vitreous carbon fiber (RVCF) to form highly permeable composite targets. We have conducted a variety of simulations of 1 GeV protons incident on various low density, highly permeable targets in order to obtain the most uniform power deposition profile. The finite-element thermal analysis code ANSYS was used to model the generation and removal of primary beam deposited heat from these targets. Radiative cooling has been found to be the most effective heat removal means for low-density refractory targets. In this report, we present examples of calculated temperature distributions in UC_2 and ZrO_2 targets using parallel and converging incident 1 GeV proton beams and illustrate the affect of beam heating and radiative cooling on the temperature distributions within a number of fibrous and composite targets.

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The structure of isobaric excitations in N=Z nuclei *

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The isobaric excitations provide invaluable information on the pairing component of effective nuclear forces in $N \sim Z$ nuclei. The aim of this paper (see Ref. [1] for details) is to discuss the necessary extensions to the mean-field approximation in order to account in a consistent manner for (**i**) the Wigner energy, (**ii**) the T=1 and T=2 states in even-even (e-e) N=Z nuclei as well as (**iii**) T=0 and T=1 states in odd-odd (o-o) N=Z nuclei. We argue that this goal can be achieved when the model includes simultanously isoscalar and isovector pairing correlations and takes into account [at least approximately] number- and isospin projection. The latter is realized within the simple cranking approximation which provides a deeper understanding of the underlying physics through a number of analogies to well known high-spin phenomena. Furthermore, we show that within such a framework also the standard BCS treatment of nuclear pairing does not longer apply. The necessary modifications are schematically drawn in Fig. 1 [left part] and can be summarized as follows: (**i**) The T=2 states in e-e nuclei and T=1 in o-o nuclei are obtained by iso-cranking the vacuum state [false vacuum for the case of o-o nucleus] so that $T_x = \sqrt{T(T+1)}$; (**ii**) The T=1 states in e-e nuclei require two-quasiparticle (2qp) excitations and subsequent iso-cranking; (**iii**) The T=0 states in o-o nuclei [or more generally the minimal isospin states T=$|N-Z|/2$ in o-o nuclei] are 2qp states. The numerical estimates of the excitation energies of T=2 and T=1 states in e-e N=Z nuclei and the difference between excitation energies of T=1 and T=0 states in o-o N=Z nuclei are shown in Fig. 1 [right panel]. The agreement between theory and experiment is indeed excellent. For further details concerning these calculations we refere reader to Ref. [1].

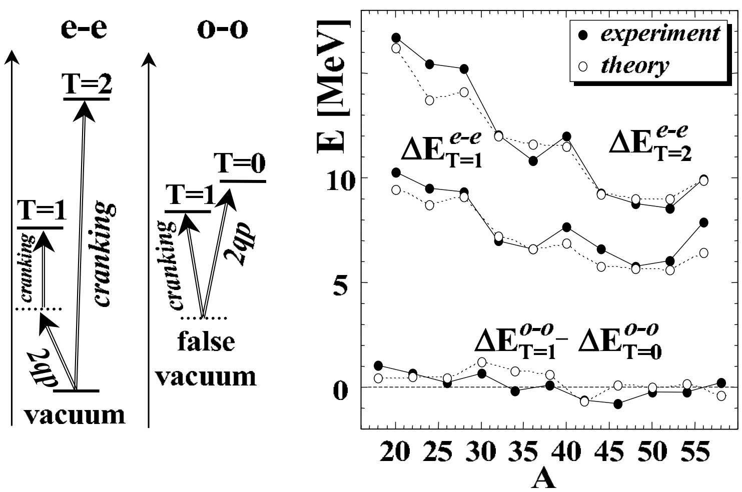

FIG. 1. Schematic illustration of the calculation scheme [left] applied to compute excitation energies of T=0,1, and 2 isobaric excitations in N=Z nuclei [right].

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Three-body observables for the low energy breakup of dripline nuclei

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Breakup reactions are frequently used to probe properties of nuclei at the edge of stability, considering their propensity for falling apart, arising from very low binding energies. From a theoretical point of view, these reactions become particularly challenging at low energies. Then, most approximations are not suitable, and a rich interplay of multistep processes, multipolarity mixing and nuclear-Coulomb interference, are present. The new generation ISOL facilities reflect the need for a solid theoretical description of low energy breakup reactions.

The great technological improvements on radioactive beams and detection systems, offering much better statistics, allow for detailed exclusive/coincidence measurements where before only integrated observables were possible to obtain. Theoretically, it is essential that the full kinematics is incorporated in the calculation and that observables for each specific experimental setup can be constructed.

In this talk, we review the Continuum Discretised Coupled Channels (CDCC) method for calculating the breakup of loosely bound projectiles $a = b + x$, where the $b + x$ continuum is explicitly included [1]. As an application, we discuss in detail the results for the breakup of ^{8}B on ^{58}Ni at 26 MeV, measured at the Notre Dame Laboratory [2-3].

The Coulomb Dissociation process has been suggested as providing an indirect measurement of low energy direct capture reactions with astrophysical interest. The Notre Dame ^{8}B breakup experiment was initially designed to determine the relative strength of the E2 component in the Coulomb Dissociation process, an important ingredient that has generated some controversy in the community [4]. The DWBA calculations for this reaction [5] predicted a very large nuclear contribution for the ^{8}B* centre of mass (c.o.m.) cross section, an effect that was already present for impact parameters as large as 20 fm. The first CDCC results for this reaction [6] found that the ^{8}B angular distribution was extremely sensitive in particular to the continuum-continuum couplings. A strong multipole nuclear-Coulomb interference was evident in those results.

From the CDCC two-body scattering amplitude it is possible to construct the triple differential cross sections (such as $d^3\sigma/d\Omega_b d\Omega_x dE_b$) with full three-body kinematics, necessary to describe the inclusive measurements in [2-3]. These observables contain more information of the physical process than the integrated c.o.m. angular cross sections reported in [6]. Also, the CDCC model space has to be larger in order to obtain stable results. We show that the three-body observables display even more clearly the importance of higher order effects present in the low energy breakup of loosely bound projectiles.

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Formation of superheavy elements in heavy-ions collisions

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The process of the synthesis of *superheavy elements* (SHEs) is not yet understood completely. In the presented work [1,2] we make an attempt to describe the cold fusion reactions of the type X + (Pb,Bi) → SHE + 1n at subbarrier and near barrier energies. The process of the formation of SHEs is subdivided into three steps. 1. The capture of two spherical nuclei and the formation of a common shape of the two touching nuclei. Low-energy surface vibrations and transfer of few nucleons are taken into account in the first step of the reaction. 2. The formation of a spherical or near spherical compound nucleus. 3. The surviving of the excited compound nucleus due to evaporation of neutrons and γ-ray emission in competition with fission. The following reactions were analyzed in detail: (^{58}Fe, ^{64}Ni, ^{70}Zn, ^{78}Ge) + ^{207}Pb, (^{50}Ti, ^{54}Cr, ^{58}Fe, ^{59}Co, ^{62,64}Ni, ^{65}Cu, ^{66,68,70}Zn, ^{71}Ga, ^{74,76,78}Ge, ^{75}As, ^{80,82}Se, ^{86}Kr, ^{87}Rb, ^{88}Sr) + ^{208}Pb, (^{58}Fe, ^{64}Ni, ^{70}Zn, ^{78}Ge) + ^{210}Pb and (^{50}Ti, ^{54}Cr, ^{58}Fe, ^{64}Ni, ^{70}Zn, ^{78}Ge, ^{86}Kr) + ^{209}Bi. The presented model describes well the available experimental cross-section data for elements with Z=104-112,118 (see fig also) and allows for predicting cross-section values for the synthesis of so far unknown heavier elements.
The SHE production in reactions with similar target and projectile [(^{124}Sn, ^{130,136}Xe) + ^{136}Xe] is considered. Reactions with similar target and projectile may be very important for determination of chemical properties of SHEs due to high reaction cross sections, see fig. The calculations are made for two different values of inner barrier, which taken place at the shape evolution stage.

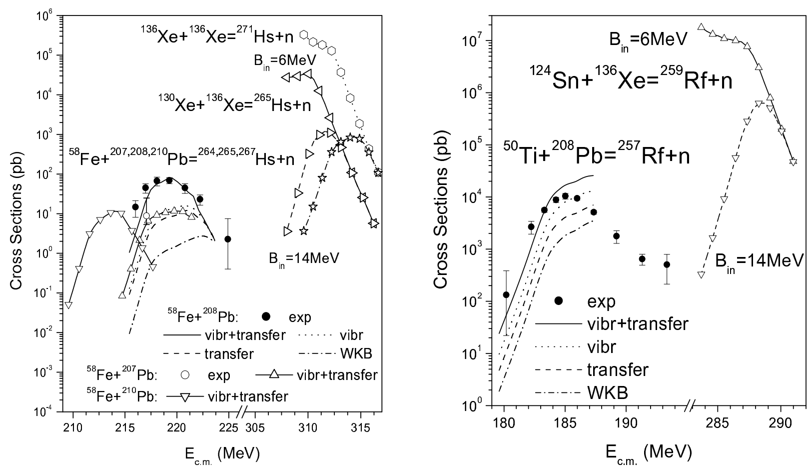

FIG. 1. Calculated excitation functions for the reactions ^{58}Fe+^{207,208,210}Pb →^{264,265,267}Hs+n and ^{130,136}Xe+^{136}Xe →^{265,271}Hs+n (left) and ^{50}Ti+^{208}Pb →^{257}Rf+n and ^{124}Sn+^{136}Xe →^{259}Hs+n (right). The continuous curve shows the results which take into account for both the low-energy 2^+ and 3^- vibrations and the neutrons transfer channels. For reactions ^{58}Fe+^{208}Pb →^{265}Hs+n and ^{50}Ti+^{208}Pb →^{257}Rf+n the dotted and the dashed curves show the results based on solely the 2^+ and 3^- vibrations and the neutron transfer channels, respectively. The results of the one-dimensional WKB approach last two reactions are shown by the dash-dotted curves. The results of calculations including both vibrations and transfer enhancements obtained for other reactions are additionally marked by symbols, see assignments in figs. The experimental data are taken from [3,4].

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Subbarrier heavy ions fusion enhanced by subbarrier nucleons transfer and subbarrier fusion of nuclei far from the β-stability line

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We discuss a semiclassical model for the description of subbarrier fusion of heavy ions which takes into account the coupling to the low-energy surface vibrational states and to the few-nucleon transfer with arbitrary reaction Q-value. The subbarrier transfer of nucleons during barrier penetration is described by using the WKB approach and does not use special proposal on the low-energy behavior of the transfer coupling. The coupling with the low-energy surface vibrations in the model is considered by using traditional simplified coupled channels approach [2,3]. This model is correct in the case of nucleons transfer with the large positive Q-value. The fusion reactions ^{32}S + ^{100}Mo, ^{36}S + ^{96}Mo, ^{28,30}Si + ^{58,62,64}Ni, ^{28}Si + ^{94,100}Mo, ^{40}Ca+^{90,96}Zr, ^{16,18,20,22,24}O + ^{58}Ni and ^{28}Si + ^{124,126,128,130,132}Sn are analyzed in the framework of this model. The calculated fusion cross section, mean angular momentum and its dispersion for these reactions are good agreed with available experimental data. It is shown that the fusion cross sections and mean angular momentum quantities are significantly enhanced by few-nucleon transfer with large positive Q-value, see fig for example.

This model is applied for the fusion reactions between nuclei near to the neutron drip line and nuclei close to the β-stability line. The neutrons transfer has extremely large positive Q-value and small values of neutrons separation energy for such collision systems. The fusion reactions ^{18,20,22,24}O + ^{58}Ni and ^{28}Si + ^{124,126,128,130,132}Sn are discussed in detail, see fig. It is shown that the subbarrier fusion cross sections and the mean angular momenta are strongly enhanced by neutrons transfer for these reactions. It is found, that the slope of energy dependence of subbarrier fusion cross section is changed due to neutron transfer. The maximums are appeared in the energy dependencies of the both mean angular momentum and its dispersion in the case of neutron transfer with positive Q-value.

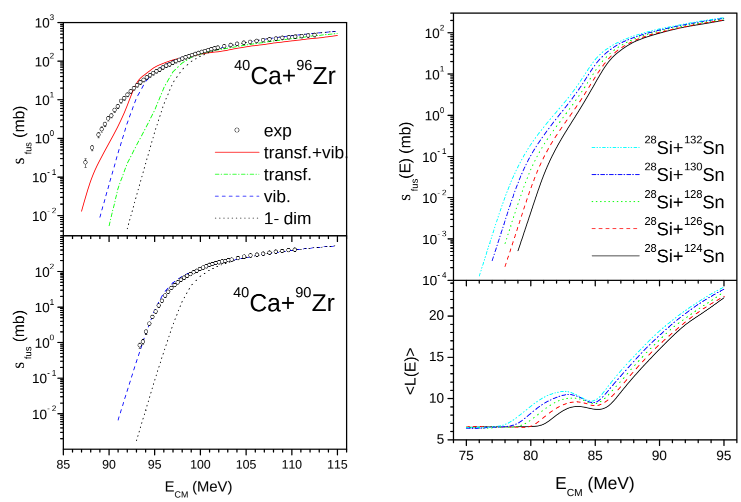

FIG. 1. Left: Fusion cross sections for the reactions ^{40}Ca+^{96}Zr (top) and ^{40}Ca+^{90}Zr (bottom). Experimental data (dots) are taken from [4]. Right: Fusion cross section (top) and mean angular momentum (bottom) for the reactions ^{28}Si+^{124,126,128,130,132}Sn.

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Recent Applications of the Shell Model Embedded in the Continuum

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Astrophysical models of stars rely strongly on certain characteristics (e.g. astrophysical factors) of nuclei involved in the chains and cycles of thermonuclear reactions [1]. Many of these reactions involve weakly stable or unstable nuclei. The influence of scattering continuum on the structure of bound and quasi-bound states in these nuclei becomes very important, making standard nuclear structure theories hard to justify. On the other hand, these nuclei are good candidates to be described as open quantum systems, where all the couplings between (quasi-)bound and scattering states are accurately taken into account.

Our aim is to apply the quantum open system formalism to describe phenomena in nuclei close to the drip lines using the Shell Model Embedded in the Continuum (SMEC). This formalism relies on the explicit division of the Hilbert space of the Schrödinger equation into two disjointed subspaces, namely the subspace of (quasi-)bound states and the subspace of scattering states [2]. At the initial stage, the first one is described by means of the usual nuclear shell model and the other one in terms of coupled channels equations. Then all the couplings between these subspaces are taken into account in terms of the residual nucleon-nucleon interaction. This modifies the scattering solutions as well as the spectroscopic quantities on the structure side. The crucial modification is that the effective Hamiltonian is no longer hermitian and resonance states acquire a width which is directly related to the imaginary parts of these Hamiltonian eigenvalues. As a result, both the structure of nuclei and cross sections are modified [3].

I report on our recent results concerning the astrophysical factor for the reaction $^{7}\mathrm{Be}(p,\gamma)^{8}\mathrm{B}$ and the elastic cross section for $^{16}\mathrm{O}(p,p)^{16}\mathrm{O}$. I present also the extension of this model for the description of emission of one or two protons from a dicrete state with the example of the second 1^- state of $^{18}\mathrm{Ne}$ [4].

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THE THEORY OF CONTROLLING THE SPONTANEOUS GAMMA-DECAY OF EXCITED AND RADIOACTIVE NUCLEI

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The paper discusses the theory of controlling gamma-radioactivity of nuclear sources and targets. For the first time we have created the theory of influence on the probability of spontaneous radiation and life-time of gamma-radioactive nuclei [1]. We have considered the general system which included the excited nucleus, the system of this nucleus electrons, the system of zero-energy (in vacuum state) electromagnetic modes and the system of N resonant or non-resonant atoms (screen) situated at the distance $L \gg \lambda_{eg}$ from the excited nucleus. The phenomenon of spontaneous nucleus decay controlling is a result of interaction of the excited nucleus with zero-energy electromagnetic modes, interaction of these modes with the atoms of screen, interaction of the excited nucleus with electrons system.

It is shown for the first time that the decay parameters greatly depend on the sign and magnitude of the radiation shift (radiation correction) of the resonance level position (nuclear analog of the Lamb shift for atom electrons.) This shift is determined by processes of nucleus interaction with all zero-energy electromagnetic field modes (the lowest by energy or ground). It was shown that the resonant screen effect in all cases appears to be more significant than for the nonresonant one. It is shown for the first time that the most influence on the nucleus spontaneous decay process will be realized in the case when the modes of the electromagnetic field in the zero-energy state, which interact with the nucleus, occur to be mutually synchronized. For this case the radiative life-time may be increased by many orders of magnitude.

The methods of the gamma-decay optimization (e.g. change by several orders of spontaneous radiative life-time) is also discussed

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Relativistic Mean-Field Description of Exotic Nuclear Structure

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Models based on the relativistic mean-field approximation provide a microscopically consistent, and yet simple and economical description of the nuclear many-body problem. By adjusting just a few model parameters: coupling constants and effective masses to global properties of simple spherical nuclei, it has been possible to describe many nuclear structure phenomena, not only in nuclei along the valley of β-stability, but also in exotic nuclei with extreme isospin values and close to the particle drip lines.

The relativistic Hartree-Bogoliubov model has been applied in studies of structure phenomena that include: the strong isospin dependence of the effective spin-orbit interaction and the resulting modification of surface properties, the suppression of the spherical $N = 28$ shell gap for neutron-rich nuclei and the related phenomenon of deformation and shape coexistence, the structure of the proton drip line nuclei in the region $31 \leq Z \leq 73$, and ground-state proton radioactivity in nuclei $53 \leq Z \leq 73$. The model has also been used to calculate parity violating elastic electron scattering on neutron-rich nuclei, and neutron density distributions for atomic parity nonconservation experiments. The relativistic random phase approximation, based on effective mean-field Lagrangians with nonlinear meson self-interaction terms, has been used in the analysis of the dynamics of isoscalar dipole modes and of the structure of pygmy resonances.

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THE METHOD OF SPATIAL 3-D DETECTING OF REMOTE OR SOLITARY RADIOACTIVE SOURCES BY CORRELATION OF INTENSITY OF RADIATION

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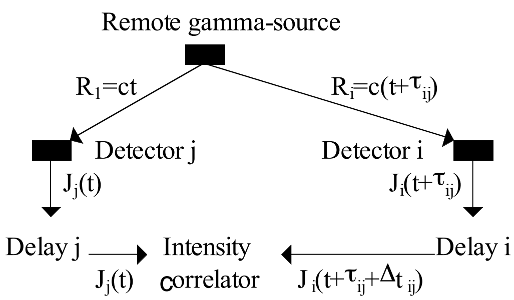
The intensity correlation method of spatial and angular (three-dimensional) location of solitary or remote sources of gamma-radiation or neutrons is suggested and studied. The main idea of the method is based on the phenomenon of pair correlation of intensities $J_j(t) = \varepsilon_j |\xi_j(t)|^2$ and $J_i(t+\tau_{ij}) = \varepsilon_i |\xi_i(t+\tau_{ij})|^2$ of gamma-radiation measured by two separated detectors i and j [1]. Here $\xi_k(t) = \Sigma_n \Psi_k(\mathbf{R}_k, t-t_{kn})$ are sums of pulse spherical waves $\Psi_k(\mathbf{R}_k, t-t_{kn}) \equiv F(t-t_{kn})\exp(i\mathbf{kR}_k)/R_k$ of gamma-radiation coming from a remote gamma-source, location $\mathbf{r}_o$ of which is to be found. The pair correlation function $K_{ij}(\tau_{ij})$ of intensities $J_j(t)$ and $J_i(t+\tau_{ij})$ for two spatially separated independent detectors, situated at $\mathbf{r}_i = \mathbf{R}_i+\mathbf{r}_o$, $\mathbf{r}_j = \mathbf{R}_j+\mathbf{r}_o$ and having the effectiveness ε_i and ε_j of the quantum detecting, equals



$$K_{ij}(\tau_{ij}) = < J_i(t)\, J_j(t+\tau_{ij})> - < J_i(t)> < J_j(t+\tau_{ij})>.$$

Here $\tau_{ij} = (R_i-R_j)/c$ is the time-delay of measured intensities $J_j(t)$ and $J_i(t+\tau_{ij})$ in different detectors i and j from the same remote detected gamma-source.

For the studied case of quasi-stationary source of gamma-radiation and for the usual case of the random Gaussian process of quanta detecting $\xi_k(t)$ the correlation function of intensity has the form

$$K_{ij}(\tau_{ij}) = \varepsilon_i\varepsilon_j \{<\xi_i(t)\, \xi_i^*(t)> <\xi_j(t+\tau_{ij})\, \xi_j^*(t+\tau_{ij})> + <\xi_i(t)\, \xi_j(t+\tau_{ij})> <\xi_i^*(t)\, \xi_j^*(t+\tau_{ij})> + <\xi_i(t)\, \xi_j^*(t+\tau_{ij})> <\xi_i^*(t)\, \xi_j(t+\tau_{ij})>\} - <J_i(t)> <J_j(t+\tau_{ij})> = \varepsilon_i\varepsilon_j |<\xi_i(t)\, \xi_j^*(t+\tau_{ij})>|^2 = <n_i> <n_j> \left|\int_{-\Delta\omega/2}^{\Delta\omega/2} |F(\omega)|^2 \exp(-i\omega\tau_{ij})\, d\omega\right|^2.$$

Here $F(\omega) = \int_{-\infty}^{\infty} F(t)\exp(-i\omega t)\, dt$; $|F(\omega)|^2$ - the spectral intensity (having the spectral half-width $\delta\omega$) of the single detected gamma-quantum after detector (on the exit of detector); $\Delta\omega$ - the spectral band of the intensity correlator (signal acquisition and processing system); $<n_i>$ and $<n_j>$ are the averaged quantity of detected gamma-quanta in the detectors i and j.

For the usual case $\Delta\omega<\delta\omega$ we have the correlation function

$$K_{ij}(\tau_{ij}) \approx 4<n_i> <n_j> |F(0)|^4 |\sin(\Delta\omega\tau_{ij})/\tau_{ij}|^2.$$

The maximum value of this correlation function is equal $K_{ij}(0)= 4<n_i> <n_j> |F(0)|^4 |\Delta\omega|^2$ and corresponds to the additional delay $\Delta t_{ij} = -\tau_{ij}$ of the registered intensity signal $J_i(t+\tau_{ij})$ from one of the detectors (i) or both detectors (i and j) introduced in the correlator.

For three-dimensional location of the remote source of gamma-radiation it is necessary to use three or more spatially separated independent detectors, situated at $\mathbf{r}_1$, $\mathbf{r}_2$, $\mathbf{r}_3$,..., and three or more independent intensity correlators. For this case the position of the detected remote source $\mathbf{r_0}=\{x_0, y_0, z_0\}$ of gamma-radiation may be calculated using the system of equations

$$[(x_i- x_0)^2+(y_i- y_0)^2+(z_i-z_0)^2]^{1/2} +c\Delta t_{ij} = [(x_j- x_0)^2+(y_j - y_0)^2+(z_j-z_0)^2]^{1/2};$$

for maximum values of correlation functions $K_{ij}(0)$ for different pairs ij ($i\neq j$=1,2,3...) of gamma-detectors.

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HFB theory for nuclei near the drip-lines: continuum coupling *

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Near the neutron or proton drip lines, large pairing correlations are expected which can no longer be described by a small residual interaction. Furthermore, the outermost nucleons are weakly bound (which implies a large spatial extent), and they are strongly coupled to the particle continuum. These features represent major challenges for the mean field theories.

We solve the Hartree-Fock-Bogoliubov equations for deformed, axially symmetric even-even nuclei on a two-dimensional lattice. High accuracy is achieved by representing the operators and wavefunctions in terms of Basis-Splines; a combination of the Galerkin and collocation method is utilized [1]. This work represents a natural extension of the 1-D calculations for spherical nuclei by Dobaczewski et al. [2]. Test results for ^{22}Ne using a Skyrme mean field and a constant pairing Hamiltonian are shown in Fig. 1. The HFB lattice Hamiltonian has been directly diagonalized using LAPACK yielding a quasiparticle energy spectrum up to $E_n = 2000$ MeV. In calculating observables, we cut off this spectrum at an equivalent s.p. energy of about 60 MeV. These first results are a successful test of our numerical algorithm to perform pairing calculations in two dimensions for nuclei near the drip lines. Calculations with realistic pairing interactions (density-dependent delta-forces) are now underway.

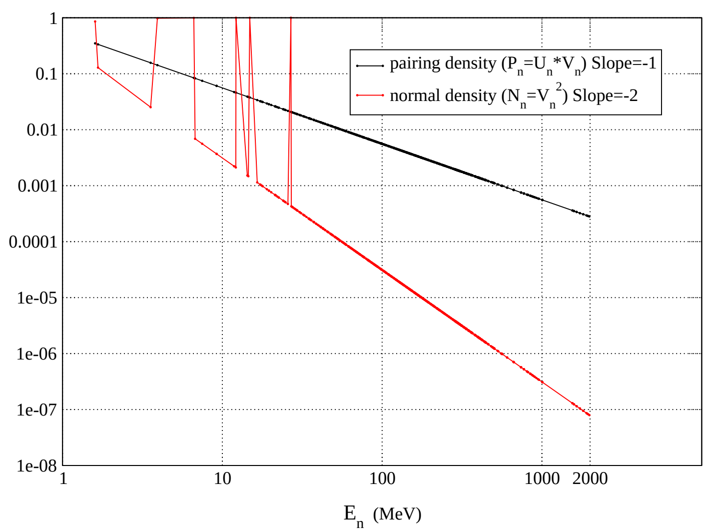

FIG. 1. Quasiparticle energy spectrum of normal and paring densities.

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Possibilities to describe the production of rare isotopes close to drip-line in the Fermi energy domain *

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In the Fermi energy domain, the production of rare isotopes with large neutron/proton excess has to be considered as a two step process including the production of excited nucleus in the first stage and its de-excitation in the latter stage. The deep inelastic transfer and the incomplete fusion determined by a geometric overlap of nuclei are assumed as a production mechanisms of excited nuclei. A cooling via emission of fast pre-equilibrium particles is introduced in an approximate way using simple phenomenological assumptions. Various modes of de-excitation ranging from particle evaporation to statistical multifragmentation are examined. A possibility to describe a broad range of data in both symmetric and asymmetric systems and in normal and inverse kinematics will be discussed (see also [1]).

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Isospin Dynamics in Fusion Processes: Collective Dipole Bremsstrahlung

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We evaluate the pre-equilibrium Dipole photon radiation accompanying the fusion of charge asymmetric ions. Following a semiclassical approach we estimate the collective bremsstrahlung emission in a fusion dynamics described via a microscopic quantum transport model.

We study energy, charge and mass dependence of this contribution to the Giant Dipole Resonance (GDR) photon emission in hot nuclei.

The dynamical origin of the extra GDR strength will show up in a characteristic anisotropy of the dipole γ-emission, being this dipole oscillation constrained on the reaction plane.

We stress the interest in experiments with the new available radioactive beams. Apart the importance of a better analysis of this new pre-equilibrium phenomenon, we suggest the possibility of using such characteristic signal to select fusion paths in dissipative collisions with exotic nuclei.

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Damping of giant resonances in non-Markovian approach *

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The relaxation mechanisms of collective motion and temperature dependence of the damping widths in many-body systems have been much investigated during recent years. In this contribution the damping widths of the giant dipole resonances in heated nuclei are calculated and discussed on the base of the semiclassical second RPA[1] as well as within the nuclear fluid-dynamics method[2,3].

The expression for collisional relaxation time, τ_c, is taken within framework of two approaches: *i*) it is calculated using the non- Markovian collision integral of the Landau-Vlasov transport equation[4]; *ii)* the time τ_c is obtained on the base of decay rates of the interparticle interactions within framework of the exciton model[5]. The collision integral in approach *i)* is taken in a modified form with allowance for reaching the local equilibrium in system. In particular, in the approach *ii)* a dependence of the $\tau_c(\omega, T)$ on collective vibration frequency and the temperature agrees with that one from[6], when the mean square matrix element of interparticle collision from[7] is used.

The width of the giant dipole resonance is calculated as a function of excitation energy for the Sn and Pb nuclei region. The widths calculated within nuclear fluid-dynamics method[2,3] show much weaker variation with temperature in comparison with those ones according to the semiclassical $SRPA$.

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ANISOTROPIC ALPHA DECAY AND NUCLEAR DEFORMATIONS

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A renewed interest has been raised by recent experimental results on *alpha* anisotropy on Fr and Pa isotopes [1]. A miscroscopic description of the alpha decay of the odd mass nuclei for axially deformed nuclei was proposed few years ago [2]. Realistic mean field + pairing residual interaction within BCS approximation in a very large single particle basis was used. Systematic calculations for At and Rn isotopes, as well as for ^{221}Fr, were performed. The barrier penetration process is treated within the WKB approximation. In the Table the calculated widths and predicted values of the function $W(\vartheta) = 1 + \sum_{L=2,4} Q_L B_L U_L A_L P_L(cos\vartheta)$ are reported for a few selected cases. Here A_L are the theoretical A-coefficients, Q_L are coefficients that take into account the dimensions of the sourse and detectors, B_L describes the orientation of the nuclei and U_L corrects B_L for unobserved intermediate transitions. A pronounced anisotropic emission of the alpha particles is predicted, as a function of the deformation for deformed nuclei. Calculations were initially performed for At and Rn isotopes. We found that alpha decay is an excellent tool to probe intrinsic deformations in nuclei.

New calculations on Pa - isotopes, making use of a improved single particle basis [3] were performed. They show a very nice agreement with the new data [1]. The new approach uses a single particle basis consisting of two different harmonic oscillator potentials and allows to reproduce, in even-even nuclei, the experimental total widths for α decay within 20%. Comparison with other microscopic approaches will be presented.

	β_2	Γ_{exp}	Γ_{th}	A_2	A_4	$W(0^o)$	$W(90^o)$	$\frac{W(0^o)}{W(90^o)}$
$^{205}_{86}Rn$	0.005	2.68(-24)	6.76(-25)	0.022	0.000	1.022	0.989	1.034
$^{207}_{86}Rn$	0.016	8.17(-25)	8.50(-26)	0.076	0.000	1.076	0.962	1.118
$^{209}_{86}Rn$	0.023	2.62(-25)	4.27(-26)	0.111	0.001	1.112	0.944	1.177
$^{219}_{86}Rn$	0.081	1.15(-22)	2.05(-22)	0.398	0.008	1.406	0.804	1.749
$^{221}_{87}Fr$	0.069	1.55(-24)	1.08(-24)	-0.288	0.005	0.717	1.146	0.626
$^{241}_{95}Am$	0.220 0.08	3.34(-34)	2.09(-34)	1.158	0.070	1.500	0.736	2.038
$^{243}_{95}Am$	0.220 0.08	1.96(-33)	1.17(-33)	-	-	-	-	-

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WEAK PAIRING CORRELATIONS WITHIN A SELF-CONSISTENT APPROACH CONSERVING EXPLICITELY THE PARTICLE NUMBER

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The description of the structure and elementary excitations of atomic nuclei within the HFB or its BCS approximation, suffers from well-known deficiencies in weak pairing regimes. Such situations are encountered for instance at or near (sub-)shell closures, at high enough angular velocities and for quasi-particle states such as high-K isomers. These defects have been attributed to the particle number particle breaking inherent to the HFB approximation. In this contribution we would like to propose and illustrate a tractable method which is free from these difficulties in that it conserves explicitly the particle number yet preserves the computational environment of state of the art HFB or HF plus BCS calculations, using e.g. Skyrme or Gogny current parametrisations of the effective force. Its purpose may be summarized by qualifying it of highly truncated self-consistent deformed shell model calculations. It starts from the hamiltonian H = K + v, where K is the kinetic energy and v the 2-body effective force. Introducing a mean field V one may trivially rewrite H as H = K + V + w, where w = v – V is the residual interaction. The latter is diagonalized in a n-particle/n'-hole basis built on the sp eigenstates associated with the 1-body Hamiltonian H = K + V. The rate of convergence of the solution in terms of the complexity factors of the considered basis states (n or n') is of course contingent upon a judicious choice of V. This potential is defined as the convolution of the 1-body reduced density matrix ρ associated with the correlated wavefunction Ψ in a HF fashion, i.e. V = tr ρ v', where v' stands for the antisymetrized interaction v. The problem has thus to be solved self-consistently so as to incorporate in V all the 1-body properties associated with Ψ. We have performed such calculations using the standard SIII Skyrme force [1] for the p-h channel and a delta force fitted for BCS calculations for the p-p channel [2]. The discussion of our results will include some general aspects of our method as the fast convergence of the calculations. Indeed, for 0^+ solutions, we have shown that 3p-3h configurations do not add any significant physical results while pair transfers, in accordance with the physical ideas supporting the BCS ansatz, are found to be the dominant correlation mechanism. We will also show that near some shell closures, the pairing correlations which are vanishing in a BCS approach, are quenched yet still present in our approach. Various isomeric state energies of the ^{178}Hf nucleus are reproduced within 100-200 keV, demonstrating thus the ability of our approach to deal, using the **same** Hamiltonian, with strong pairing solutions as well as with solutions where the pairing correlations are reduced due to the well-known blocking effect in qp isomers. To conclude, we stress that the method which is presented here, while respecting an important conservation rule, appears to be both tractable and physically successful.

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Molecular-like Structure in Light Neutron-rich Nuclei

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The survey of the molecule-like structure is one of the most challenging subjects in light neutron-rich nuclei. In Be isotopes, recently, decay into fragments of He isotopes (^{4}He, ^{6}He, ^{8}He) has been observed from the excited states of ^{10}Be and ^{12}Be, and the presence of two-center configuration is suggested.

As for the multi-cluster configurations in light α-nuclei beyond the two-center systems, the existence of $N\alpha$ states has been predicted around the threshold energy in the so-called Ikeda diagram. For example, it has been suggested that the second 0^+ state of ^{12}C has 3α-like molecular configuration. However, according to a lot of theoretical analyses the state is not necessary to have a linear-chain of 3α, but is described as a weak-coupling state with triangular shape or ^{8}Be+α configuration.

Recently, the discussions of the well-developed cluster structure are extended to the neutron-rich nuclei, and the role of valence neutrons which stabilize the linear-chain structure has been pointed out. For example, von Oertzen has extended his analyses for the molecular structure in Be isotopes [1] to C isotopes, and the linear-chain state consisting of 3α and valence neurons around it has been speculated. Even if the 3α-system without valence neutrons (^{12}C) does not have a linear-chain structure, the valence neutrons around it are expected to increase the binding energy and stabilize the linear-chain state.

Here, we perform a microscopic calculation for the Be isotopes and the C isotopes and study these well-developed molecular-like states. The appearance of prolonged structure with the α-α core in ^{10}Be [2] and ^{12}Be [3] is shown to be successfully described by the α+α+n+n+·· model, where the orbits for the valence neutrons are classified based on the molecular-orbit (MO) model. In MO, the orbit of the valence neutron perpendicular to the α-α axis (z-axis) is called π-orbit, and one along the axis is called σ-orbit. The antisymmetrization imposes the forbidden space for the valence neutrons; the π-orbit must have at least one node perpendicular to the axis, and the σ-orbit must have at least two nodes since two α-clusters along the z-axis already occupy the orbitals with $n_z = 0, 1$.

In ^{10}Be, all of the observed positive-parity bands and the negative-parity bands are described within the model. The second 0^+ state of ^{10}Be has a large α-α structure with a $(1/2^+)^2$ configuration (the σ-orbit for the two valence neutrons). An enlargement of the α-α distance due to two-valence neutrons along the α-α axis makes their wave function smooth and reduces the kinetic energy drastically. A large E2 transition probability between states which belong to a rotational band (0_2^+, 2_3^+, 4_2^+) is a signature for the presence of such states. ^{12}Be is also investigated using α+α+$4n$ model, in which four valence neutrons are considered to occupy the $(3/2^-)^2(1/2^+)^2$ configuration. The energy surface of ^{12}Be is shown to exhibit similar characteristics, that the remarkable α clustering makes the binding of the state with $(3/2^-)^2(1/2^+)^2$ configuration properly stronger in comparison with the closed p-shell $(3/2^-)^2(1/2^-)^2$ configuration. This effect is suggested to play a crucial role in accounting for the dissipation of the $N = 8$ magic number in ^{12}Be.

The molecule-like structure of the C isotopes is investigated using a microscopic α+α+α+n+n+$\cdots$ model, where both π-orbit and σ-orbit are introduced around three α-clusters. The valence neutrons which occupy the π-orbit increase the binding energy and stabilize the linear-chain of 3α against the breathing-like break-up. However, ^{14}C with the π-orbit does not show clear minimal energy against the bending-like path. The combination of the valence neutrons in the π- and the σ-orbit is promising to stabilize the linear-chain state against the breathing- and bending- modes, and it is found that the excited states of ^{16}C is one of the most promising candidates for such structure.

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Proton Emission from Odd–Even and Odd–Odd Deformed Drip–Line Nuclei

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One of the most exciting subjects in contemporary nuclear physics is the search for the limits of stability of nuclei. Recent measurements on spherical [1] and deformed proton emitters, in the region of heavy nuclei with $50 < Z < 82$, make possible to define almost completely the borders of proton stability. Important aspects of nuclear structure can be learned from proton decay, since it is a probe for small components of the wave functions of the decaying states and helps to determine the deformation of nuclei and the angular momentum of the ground state [2]. The theoretical description of proton emission from spherical systems was studied by various authors [1,3], and the experimental results are well reproduced within these models. In the case of deformed nuclei, to study proton emission, one has to determine resonances in deformed system. The search of complex energy eigenvalues in a nonspherical system was solved only recently [4]. The Schrödinger equation was solved exactly [4] for a deformed Saxon–Woods potential with a deformed spin-orbit term, imposing outgoing wave boundary conditions. The states obtained with this procedure are the Nilsson bound states and resonances.
Assuming that the proton moves in a single particle Nilsson level, we have developed a model that leads to the exact evaluation of the half–life for the decay. The model was applied to all measured odd [2] and even [5] deformed decaying nuclei, considering deformed those systems where spherical calculations provide unreasonable spectroscopic factors.
The available data were accurately and consistently reproduced for all deformed proton emitters from the ground and isomeric states and the fine structure decay. The calculations provide information on the deformation and angular momentum J of the decaying nuclei, giving unambiguous assignments to the decaying states. This type of information might be difficult to extract using other probes in this unstable mass region. Our results support the nuclear structure predictions of ref. [6] for nuclei at the proton drip line.

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Microscopic coupled-channel study of molecular resonances in ^{12}Be

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Recently, the breakup experiment of ^{12}Be into ^{6}He+^{6}He has been performed using a 378 MeV ^{12}Be beam [1]. The results indicate the existence of the exotic ^{6}He+^{6}He molecular states in the 10 to 25 MeV excitation energy interval, with spins in the range of $4\hbar$ to $8\hbar$.

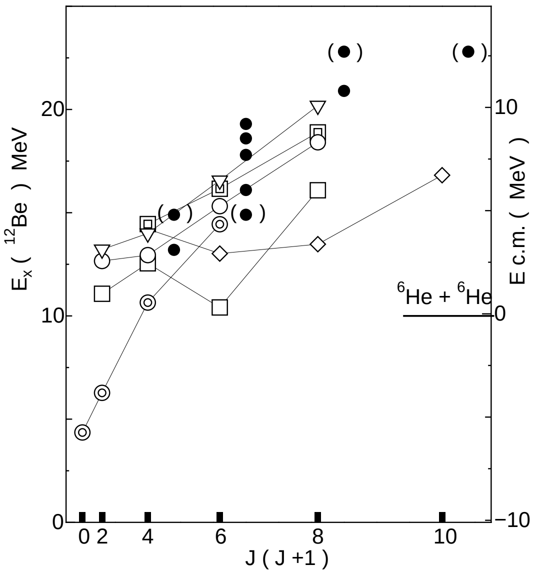

Fig. 1. Molecular bands of the ^{6}He+^{6}He system obtained by CC calculation. The solid squares in parentheses represent the spin unknown states observed in breakup experiment [1]. See text for details about each molecular band.

In order to investigate the nuclear structure of these exotic molecular states in ^{12}Be, we perform a microscopic coupled-channel (CC) calculation of ^{6}He+^{6}He elastic and inelastic scattering. We use the double-folding interactions based on the realistic nucleon-nucleon interaction, DDM3Y. In the present CC calculation, we take into account the excitation to the 2_1^+ state (E_x=1.8 MeV) and the 2_2^+ state (E_x ∼5 MeV) of which existence is strongly suggested theoretically. The transition density to the 2_1^+ state is calculated by the microscopic ^{4}He+n+n cluster-model wave function [2], while that to the 2_2^+ one is done by the collective model assuming the quadrupole deformation [3]. The strength of the latter density is determined so as to reproduce the energy-non-weighted sum rule value of the soft-quadrupole mode from which the theoretical B(E2:$0^+ \rightarrow 2_1^+$) value is subtracted [4].

We include the elastic (0^++0^+) channel and the 0^++2_1^+, 2_1^++2_1^+, 0^++2_2^+ inelastic-channels in the CC calculation. In Fig.1, we show the ^{6}He+^{6}He molecular bands obtained by solving the CC equations. The double circles and squares show the bands in which the dominant component is the elastic and $[0^+\otimes 2_1^+]_{I=2,L=J-2}$ channels, respectively, while the bands shown by the inverse triangles, circles, diamonds and double squares have the dominant component of the $[0^+\otimes 2_2^+]_{I=2,L=J-2}$, $[2_1^+\otimes 2_1^+]_{I=4,L=J-2}$, $[2_1^+\otimes 2_1^+]_{I=4,L=J-4}$ and $[2_1^+\otimes 2_1^+]_{I=2,L=J-2}$, channels, respectively. The resonances observed in the breakup-reaction experiment are also plotted in the figure by the solid squares. It is seen that the observed resonances coincide in energy and spin with the calculated resonances belonging to the molecular bands in which the inelastic-channel components are dominant. The channel coupling effects are not so strong for the inelastic channels and the populations of the dominant channel component are less than about 60∼80 %. Therefore, the calculated molecular bands of the inelastic channels can be interpreted in terms of the so-called "weak coupling states" in which two interacting ^{6}He nuclei keep touching their surfaces and rotate to each other by almost keeping their identities.

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A MODEL STUDY OF T=0 AND T=1 PAIRING IN A SINGLE J-SHELL*

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Recent advances in experimental techniques and new possibilities that are becoming available with the use of radioactive beams, are driving a renaissance of nuclear structure studies along the N=Z line. A subject of particular interest in these nuclei is the study of isoscalar (T=0) and isovector (T=1) pairing correlations. For more than 40 years since the initial suggestion by Bohr, Mottelson and Pines [1] of a pairing mechanism in the nucleus, analogous to that observed in superconductors, a wealth of experimental data has been accumulated supporting the important role of *nn* and *pp* "Cooper pairs". In contrast to this well established phenomenon, we are still searching for a clear signature of the formation of correlated *np* pairs.

In this work we present a study of competing isovector and isocalar pairing correlations within the framework of a spherical single j-shell space. We used the code OXBASH [2] introducing an effective two-body force of the form $V = xV_{J=0}^{T=1} + (1-x)V_{J=1}^{T=0}$, to model the mixture of the two types of interactions by the value of x. We will compare our results with those of a single *l*-shell [3], stressing the most relevant differences between the two cases. In particular, we find that an appreciable component of isoscalar pairing (~50%) favors a ground state with aligned spin.

We will also discuss the behavior of binding energy differences and relative excitation energies of the lowest T=0 and T=1 states in odd-odd N=Z nuclei in the presence of a *deuteron-like* (*np*, T=0) pair condensate. A connection with experimental data will be made.

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The performance of self-consistent models in the realm of exotic nuclei

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Continously developing experimental facilities produced in the last two decades a world of new nuclei outside the valley of stability. The new data thus acquired constitute severe probes for existing nuclear structure models, the liquid-drop model plus shell corrections (macroscopic-microscopic method) and the various brands of self-consistent mean-field models. All these models employ a great deal of phenomenological adjustment. New nuclei help enormously to scrutinise the predictive power of these various models and to improve on hitherto vaguely fixed aspects. The poster will discuss several key data and their value to discriminate models, e.g. binding of super-heavy elements, two-nucleon separation energies, isotopic shifts, neutron radii, or odd-even staggering.

Probably the most popular from the self-consistent models are the Skyrme-Hartree-Fock method (SHF), the Gogny force, and the relativistic mean field model (RMF). We will discuss and compare SHF and RMF. In both cases, the actual model parameters are adjusted phenomenologically and thus there exists a great variety of different parametrisations within SHF as well as RMF. The presentation will cover several different parametrisations to exemplify the versatility of the models and to evaluate possible systematic differences between SHF and RMF. We will compare formal aspects as well as the descriptive power. For example: the RMF has proven to be superior what spin-orbit properties is concerned while the SHF is more versatile in iso-vector trends; both aspects play a role in extrapolations to exotic nuclei. This hints that both models still deserve improvements. Data from exotic nuclei are crucial for this further development.

Atomic Electric Dipole Moments and Time-Reversal Symmetry Violation: Role of Ocupole Collectivity *

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Time-reversal symmetry violation has so far been observed only in kaons [1], and its orgin is still unclear. The search for electric dipole moments (EDMs) of neutral atoms provides a complementary window onto the same phenomenon. Experiments that search for EDMs can benefit by using atoms in which the moments can be enhanced by structural effects in either the atom or the nucleus.

Here we discuss an enhancement of the EDM in atoms whose nuclei have strong octupole correlations in the ground state [2,3]. After giving a rough estimate of the size of the enhancement, which depends sensitively on the matrix element of the time-reversal-violating nucleon-nucleon interaction, we discuss self-consistent mean-field calculations designed to capture the enhancement more precisely. We conclude that a source of radioactive octupole-deformed nuclei such as ^{225}Ra and ^{223}Rn would be worthwhile.

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Rotational Properties of Neutron Drip-Line Ne and Mg Nuclei *

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Moving away from stable nuclei by adding either protons or neutrons, one finally reaches the particle drip lines. The neutron-rich, weakly-bound nuclei close to the neutron drip line have very unusual properties: they are large, diffused, and superfluid [1].

In this work, the systematic behavior of rotational bands in deformed neutron-rich nuclei has been investigated with the cranked Skyrme-Hartree-Fock approach [2]. The variation of shape with rotation has been studied for the $\nu(f_{7/2})^n$ configurations in the series of even-even isotopes $^{30-38}$Ne, $^{32-40}$Mg. The Skyrme interaction SLy4 [3] has been used.

The analysis was performed in the deformation region where previous studies [4] have indicated the existence of highly deformed configurations ($\beta_2 \approx 0.35$). In particular, we studied isovector deformation effects, i.e., differences between proton and neutron deformations. According to our calculations, the quadrupole isovector deformations in the neutron-rich Ne and Mg isotopes are usually small. The strongest effect is predicted for the $\nu 3^6$ bands in the N=26 isotones at low spins. However, the difference in β_2^π and β_2^π is fairly small, it does not exceed 0.04. In all cases, proton and neutron deformations are practically identical at high angular momentum. As far as proton and neutron radii are concerned, they show very weak variation with spin. The behavior of the moments of inertia is also discussed.

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Additivity in the Highly-Deformed Rotational Bands in the A $\sim$ 130 Mass Region *

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In the present work [1] we perform theoretical analysis of rotational bands in the A $\sim$ 130 light rare-earth region. We carried out two different sets of self-consistent calculations: the cranked Skyrme Hartree-Fock (CHF) and the relativistic mean field (RMF) approach.

The Hartree-Fock analysis of the SD bands in A $\sim$ 130 nuclei has been accomplished within the cranking approximation (without pairing) with the Skyrme SLy4 interaction [2] used in the p-h channel. The self-consistent equations have been solved using the code HFODD (v1.75) [3] which employs the three-dimensional Cartesian harmonic-oscillator basis.

In the relativistic mean field (RMF) theory [4,5] the nucleus is described as a system of point-like nucleons (Dirac spinors) which interact in a relativistic covariant manner through the exchange of virtual mesons: the isoscalar-scalar σ-meson, the isoscalar-vector ω-meson and the isovector-vector ρ-meson. It is based on the one-boson exchange description of the nucleon-nucleon interaction. The RMF calculations have been performed with the NL1 parametrization [5] of the Lagrangian and the RMF-equations are solved in the basis of an anisotropic three-dimensional harmonic oscillator in Cartesian coordinates.

Our work provides a consistent understanding of the highly deformed rotational structures in the A $\sim$ 130 mass region. From our self-consistent results, we deduce effective single-particle quadrupole moments and alignments, according to Ref. [6]. The calculated quadrupole moments are compared with the recent experimental data from global lifetime measurements at GAMMASPHERE [7].

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