Letters of intent for Reaction Mechanism experiments using the GSI Slow Radioactive Beams

Approaching exotic isotopes near ^{100}Sn through cluster emission from compound nuclei

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The emission of clusters, i.e. complex fragments with charge Z such that 3<Z<12, is a strong decay mode of nuclei laying close to the proton drip-line, which have excitation energies close to 1 A · MeV. In particular, it holds a peculiar interest for moderately proton rich Ba-isotopes whereas, since the emission of a neutron becomes strongly inhibited, the residual nuclei lay very close to the N≈Z line. As it is shown in [1], the absolute cross-sections for ^{99}Cd, ^{100}In, ^{101}Sn and ^{102}In produced via ^{58}Ni+^{58}Ni fusion reactions followed by cluster emission from ^{116}Ba are at least comparable with those for the same isotopes formed through multiple light-particle decay path starting from the same compound system. Moreover, the availability of populating such exotic nuclei in excited states not accessible via multi-step light-particle evaporation is also proved [2]. Such features make cluster emission a very special pathway which can be particularly useful for nuclear-structure investigations of isotopes very close to ^{100}Sn. With the use of radioactive beams compound nuclei can be formed even further away from the valley of β-stability. ^{56}Ni-beam, for instance on a ^{58}Ni-target, would form the compound system ^{114}Ba which lay "only" one ^{12}C-decay far from ^{102}Sn, which can be populated in points of the yrast plan not approachable with other decay path.

In the wake of what so far stated, we believe that is of major interest to pursue our best endeavours to realize such kind of research as soon as the RIB will be available.

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Isospin effects on particles evaporation in the A=60 region

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The study of the isospin effects on particle evaporation, and in particular on the level density is of current interest. In the framework of the Fermi-gas model the isospin (T_3) effects on the level density can be taken into account by a distribution [1] whose width is related to the density of single- particle states at the Fermi energy. It has been shown [2] that the effective nucleon mass is expected to decrease with increasing temperature for T ≤ 2 MeV. This implies an increase, with the temperature, of the symmetry energy contribution [3] to the nuclear binding energy through the dependence on the isospin component: $E_{sym}(T)=b_{sym}(T).\ 4.T_3^2/A$. Such a predicted behaviour for the binding energy would strongly affect the dynamics of supernova collapse and explosion [3] and, therefore, it is very relevant to test it experimentally. These effects would modify the level density and would appear experimentally as a change in the particle multiplicity as well as in the relative yields of the compound nucleus decay channels and to a minor extent in the shapes of the particle spectra.

We propose to investigate on these effects starting with the study of 1p and 1n channels for the two isobar composite nuclei ^{60}Zn (N/Z=1) and ^{60}Fe (N/Z=1.3) formed at a temperature T=1.5 MeV in the reactions 240 MeV $^{4}He(^{56}Ni,1p)^{59}Cu$ and 242 MeV $^{4}He(^{56}Cr,1n)^{59}Fe$. These reactions meet the conditions of providing an high fusion cross section with a low excitation energy (15-20 MeV) of the composite systems. The latter condition is crucial to enhance the 1p and 1n channels whose expected cross sections are: σ_{1p}=500 mb and σ_{1n}=130 mb. The analysis involving only one particle allows a direct measurement of the level density [4], avoiding ambiguities involved in a comparison with a complex statistical model calculations. The relatively low angular momenta and excitation energies involved in the proposed reactions enhances the effect of the isospin on the relative yields σ_{1p}/σ_{2p} and σ_{1n}/σ_{2n} whose expected values 2.0 and 0.15, respectively. The comparison of the results for the first reaction were T_3=0 and the second one with T_3=-4 can be particularly elucidating on the role of T_3.

Particle-γ coincidences will be performed using Euroball-Euclide and Euroball-neutron detectors for the two reactions, respectively. The channels will be identified by the discrete gamma-rays of the residues and with the further condition that one (or two) protons and neutrons be detected.

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Pre-equilibrium dipole strength evaluation in N/Z different heavy-ion reactions

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Abstract

The excitation of dipole strength in the highly deformed dinucleus created in deep inelastic heavy-ion collisions was evidenced in previous experiments [1-4] performed by our group. Such an excitation gives rise to a pre-equilibrium γ-ray emission which, according to theoretical predictions, might depend on the entrance channel charge asymmetry.

Our data [5] taken in the reactions: $^{32}S+^{64}Ni$ and $^{362}S+^{58}Ni$ at E_{lab}=288 and 320 MeV respectively, differing in only the entrance channel charge asymmetry, show that while for deep inelastic events the dinucleus dipole strength increases with the entrance channel charge asymmetry, no N/Z effect was observed for fast quasi-elastic reactions. Results of the analysis of the data [6] collected in march 2000 at the LNL in the reactions: $^{32}S+^{100}Mo$ and $^{36}S+^{96}Mo$ at E_{lab}=298 and 320 MeV respectively, confirm the increase of the pre-equilibrium dipole strength excited in the composite system as a function of the initial dipole moment for fusion reactions. Data concerning the γ-ray angular distributions obtained in this experiment will give interesting information about the γ-ray dipole emission process character.

The dependence of the pre-equilibrium γ-ray emission with the incident energy is also of great importance since it gives information on the dependence of the GDR width with the nuclear excitation. If the width increases rapidly with the nuclar temperature the pre-equilibrium effect should disappear at a certain temperature. Therefore, the study of the N/Z effect for the same system of colliding ions and at differnt incident energies is an interesting problem.

The experimental apparatus for this kind of studies consists in:

a) clusters of BaF_2 scintillators for the detection of γ-rays

b) ΔE-E telescopes situated at forward angles for the detection of complex fragments emitted in peripheral reactions

c) position sensitive PPAC for the detection of evaporation residues.

We propose to continue our research program by using radioactive beams where the difference between the colliding ion dipole moment can be much larger than that obtained with stable beams and to study the N/Z effect at different incident energies for peripheral and central collisions. Beams of Si, Ar, S, Ca or heavier exotic nuclei could be interesting candidates.

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Topics of interest for Reaction Mechanism experiments using the GSI Slow Radioactive Beams

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A key question in the physics of unstable nuclei is the knowledge of the EOS for asymmetric nuclear matter away from normal conditions. We remark the effect of the symmetry term at low densities on the structure of drip line nuclei (e.g. on the neutron skin), while the knowledge in high density regions is crucial for supernovae dynamics and neutron star cooling. Effective interactions, non-relativistic as well as relativistic, are obviously tuned around normal conditions and any extrapolation suffers of a large uncertainty, and indeed we face a quite wide spectrum of predictions [1]. We expect that such bulk properties of nuclear matter can be tested in dissipative central and semicentral collisions of radioactive beams also in the low energy range, from coulomb threshold up to about 20 AMeV. The aim is to get independent laboratory controlled information on the slope of the symmetry term around saturation density, particularly important for structure calculations. This proposal is supported by some reaction dynamics predictions based on transport simulations with a new stochastic Boltzmann-Vlasov code where all isospin effects are consistently accounted for [2]. We will refer to a "asy-stiff" EOS when we are considering a potential symmetry term linearly increasing with nuclear density and to a "asy-soft" EOS when the symmetry term shows a saturation and eventually a decrease above normal density [1]:

1) Main mechanisms of dissipative collisions. - Isospin effects on the transition from fusion to deep-inelastic and eventually to neck-fragmentation. We suggest to measure the ratio of the fusion (incomplete) vs. deep-inelastic yields for semicentral (impact parameter b ofthe order of 1/2 b_max) of neutron-rich/neutron-poor ions, with roughly the same initial masses, in the energy regionbetween 10 and 20 AMeV. Particularly interesting the skin dynamics where we can reach relatively high asymmetries. The asy-soft choice leads to a less repulsive dynamics for neutronrich colliding ions, which means a larger incomplete fusion cross section at medium energies. For proton rich systems we expect just the opposite [2]. The "orbiting", excitation energies and widths (in charge, angle etc..) of the deep-inelastic fragments should also be affected by the symmetry term. In this respect it could be quite interesting to measure the fraction of neck-fragmentation events and to select fast PLF/TLF-fission processes [3].

2) Pre-equilibrium effects. - Gamma detection: the "Dynamical Dipole effect"We like to stress the interest in experiments on the pre-equilibrium GDR gamma emission, ruled by the charge asymmetry in the entrance channel and by the fusion dynamics in the energy range 5-20 AMeV [4]. We can get important information on the isospin mixing dynamics and on the damping of a Giant Dipole mode built on a hot and deformed dinuclear system and again on the symmetry term around saturation conditions. From dynamical simulations we can get an absolute evaluation of the effect, including its energy and mass dependence [5]. The dynamical dipole radiation could be a relevant cooling mechanism in "warm" fusion paths, of interest for the synthesis of heavy elements. Moreover for its characteristic angular anisotropy can be used to select fusion events in reactions induced by radioactive beams. -Particle detection: N/Z content We suggest to study prompt neutron "bursts" for neutron-rich systems: interplay between compressibility of asymmetric nuclear matter, NN cross sections and symmetry term of the mean field. The isospin effect should be observed also in the yields of neutron rich light ions emitted before equilibration. We remind that in the asy-stiff choice the potential seen by neutrons is more repulsive at densities above ρ_0 and less repulsive below (the opposite with the asy-stiff). Moreover the prompt particle emission is strongly influenced by the momentum dependence of the mean field, in particular in the spectrum slopes and in the Fermi jet contributions [6,7]. We can foresee the possibility of getting independent information on the isospin dependence of effective masses, of importance also for the level density parameter used in evaporation studies of excited asymmetric nuclei.

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Fusion and fission reaction cross sections initiated by radioactive beams might be enhanced by coupling to breakup channels. This is more probable in the case of two-neutron halo projectiles such as ^{11}Li, ^{6}He, ^{12}Be. In fact after the prompt emission of the first neutron, the second will decay in flight from a resonance state. The same could happen to proton halo states because of the Coulomb barrier effect. The final state interaction of this resonant neutron/proton with its initial core, as well as with the target nucleus, might create dorway states. Such processes are expected to be important at energies not too large with respect to the Coulomb barrier. It would be important to perform fully exclusive experiments in which one would measure in coincidence the neutrons/protons and the core, as well as gamma-rays from projectile and target. This would allow reconstruction of the target final state and of the projectile initial state. It would be important to clarify if simple one or two neutron/proton breakup reactions are still possible in correspondence to slightly deep inelastic core-target collisions, due to trajectories with impact parameters smaller than the strong absorption radius.