Production of neutron-rich isotopes in ^{82}Se+^{238}U grazing reaction

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The reactions at the grazing angle between heavy ions at energies close to the Coulomb barrier are presently considered as a valuable tool for the production of nuclei far from stability [1, 2], particularly in the neutron-rich area. Recent high mass-resolution experiments demonstrated that one could observe the transfer of up to six proton stripping (-6p) and six neutron pick-up (+6n) channels with cross sections down to $\simeq$ 50-100 μb (see Ref. [3] and references therein). The difficulty in populating very neutron-rich isotopes via grazing reactions resides not only in the low primary cross sections. Since the Q-values get more and more negative as more nucleons are transferred, the evaporative effects may significantly lower the final yields for very neutron-rich nuclei. The evaporation of nucleons from the primary fragments has been shown to play an important role in multinucleon transfer reactions even at energies very close to the Coulomb barrier. Studies performed using deep inelastic processes with heavy ions show that the mass-integrated nuclear-charge distribution widens as a function of the total kinetic energy loss, thus demostrating the possibility to reach a broad range of final products. These experiments were performed using high-efficiency particle detectors, but were characterized by very poor mass resolution for heavy ions. Good mass resolution can be achieved, without loss of detection efficiency, with the present new generation spectrometers [4]. Therefore, it is now possible to measure the production cross-section for most of the nuclides coming out from quasi-elastic and deep-inelastic reactions. A detailed knowledge of (A,Z) yields is important both from theoretical and experimental point of view. It will let us understand better the competing quasi-elastic and deep-inelastic reaction mechanisms, and their relative contribution to the cross section for each reaction product. Moreover, reliable values for the production cross-sections are extremely important when planning experiments aiming at studying the structure of very exotic nuclei. In this context we felt interesting to measure the yield of the nuclei populated in ^{82}Se+^{238}U at an energy close to the Coulomb barrier. The neutron-rich (stable) ^{82}Se projectile (Z=34,N=48) is a suitable candidate to investigate, via multiproton stripping channels, the population yield of neutron-rich nuclei in the Ni-Ge region.

In a first measurement [5], a ^{82}Se beam has been accelerated at E_L=500 MeV with the Tandem+ALPI booster of the Laboratori Nazionali di Legnaro and with an average current of $\simeq$ 0.6 pnA onto a ^{238}U target with a thickness of $\simeq 200\mu g/cm^2$. Light reaction products have been identified with the spectrometer PISOLO [6]. We measured differential cross sections at six angles in the range $\theta_{lab} = 50^o$-82^o so as to cover most of the total transfer flux. Absolute normalization of cross sections was determined by detecting elastically scattered Se nuclei on four solid state SSBD monitor detectors placed at $\theta_L = 16.5^o$ with respect to the beam-axis inside a sliding-seal scattering chamber connected to the spectrometer. Using PISOLO, mass identification turned out to be very difficult, due to the limitation of the spectrometer mass resolution for these heavy ions and the poor statistics. For these reasons, we could reliably extract only mass-integrated cross-sections for several Z values close to the projectile.

The second experiment, using the PRISMA/CLARA [4, 7] setup, has been performed in a $\simeq$ 3 days run with a ^{82}Se beam at the same energy and with an average intensity of 3 pnA onto a 200 μg/cm^2 ^{238}U strip (1 mm) target sandwitched between two 20 μg/cm^2 C-layers. Projectile-like products have been selected around the grazing angle θ_{lab}=64^o.

Ions detected in PRISMA are identified with their atomic number Z, mass A, and velocity vector. The mass resolution obtained in the present experiment after trajectory reconstruction is 1/180, sufficient to have a very clean discrimination of all the detected projectile-like isotopes. PRISMA has been coupled to the CLARA γ-array, which allows to perform γ-particle coincidences. In this way, we had the possibility, looking at γ spectra, to verify the accuracy of A and Z selection achieved with PRISMA, and also to obtain valuable γ-spectroscopy in-

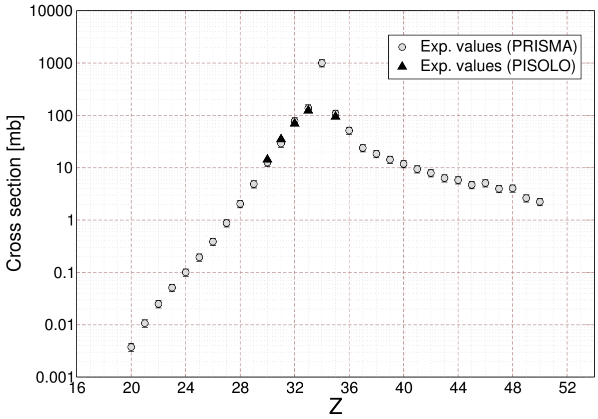

FIG. 1: *Mass, angle and Q-value integrated cross sections for the $^{82}Se+^{238}U$ reaction measured with the spectrometers PRISMA and PISOLO.*

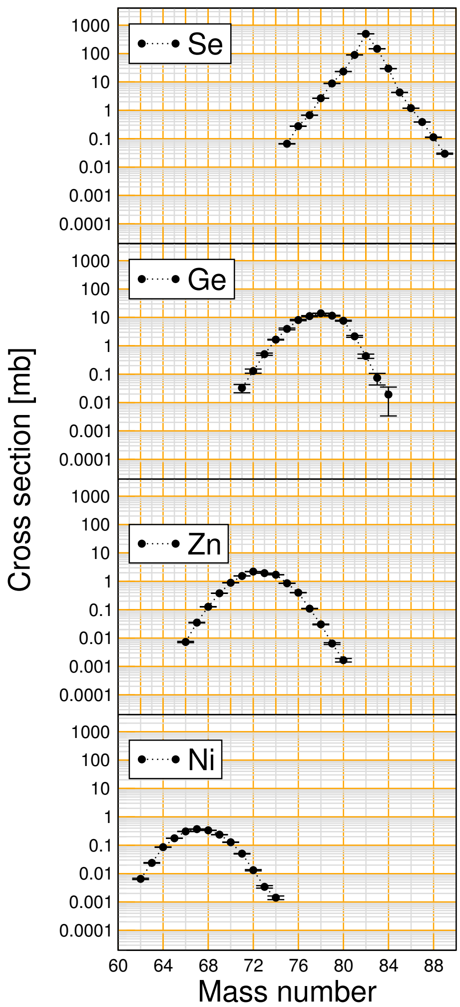

FIG. 2: *Angle and Q-value integrated total cross sections for Z=28,30,32 and 34 isotopes, measured with PRISMA in the reaction $^{82}Se+^{238}U$.*

formation for many of the neutron-rich nuclei produced in the reaction. The angle and Q-value integrated total cross sections measured with PISOLO are shown in Fig.[1] toghether with those derived from the measurement with PRISMA, which have been normalized to the mass integrated proton stripping channels derived with PISOLO. One observes, on the stripping side, a smooth decrease of total cross section by a factor $\simeq 3$ when decreasing Z by one unit. The sensitivity of PRISMA allowed to measure nuclei down to Ca isotopes, corresponding to the removal of 14 protons and to a cross section of $\simeq 1$ μb. On the pick-up side, the behaviour is different, mainly due to the overlap with fission events from the ^{238}U target. Fig.[2] shows the mass distribution for different isotopes obtained after gating on specific Z. For Se-like nuclei (Z=34) one sees events corresponding to pick-up as well as stripping of neutrons. One can see that it is possible to observe neutron-rich isotopes like, for instance, the $N = 50$ ^{82}Ge(-2p+2n) and ^{80}Zn(-4p+2n) , with cross-sections of 400 μb and 2 μb, respectively. The shapes of the mass distributions along the proton stripping channels are quite similar, with a width of $\simeq 4$ mass units. The mass distributions tend to shift towards lower neutron numbers as more protons are removed from the projectile, in agreement with the trend already observed in other systems, in particular the ^{64}Ni+^{238}U case [8]. As neutron stripping channels are not favoured from optimum Q-value arguments, we interpret this behaviour as the onset of deep inelastic processes, besides the effect of neutron evaporation from the primary fragments. Theoretical calculations [9] for comparison with the experimental mass-distribution obtained over more than 20 atomic numbers in this PRISMA/CLARA measurement are currently in progress.

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