Cross sections measurement in fusion reactions ^{36}Ar(^{148}Sm; xn)

M. Schädel [1], W. Brüchle [1], E. Jäger [1], A. Popeko [2], S. Reitmeier [3], E. Schimpf [1],
R. Sagaidak [2], A. Shutov [2], A. Türler [3], A. Yakushev [3], A. Yeremin [1]

[1] Gesellschaft für Schwerionenforschung mbH, Darmstadt, Germany
[2] Flerov Laboratory of Nuclear Reactions JINR, Dubna, Russia
[3] Institut für Radiochemie TUM, München, Germany

On the way to neutron-rich superheavy elements (SHE) very exciting results were observed in ^{48}Ca induced reactions with heavy actinide targets[1]. These SHE isotopes have life times several orders of magnitude longer than isotopes produced in “cold fusion” reactions. In the future, reactions with neutron-rich radioactive ion-beams may open a possible path for a further increase of the neutron excess in SHE nuclides. New facilities for radioactive beams are operational or will be constructed. It is of great interest to pursue the "hot-fusion" path and to investigate the projectile-isospin dependence of heavy element fusion-evaporation residue cross sections at Coulomb barrier energies. For this, it is planned to exploit the potential of a facility like SPIRAL which shall provide n-rich radioactive ion beams. Presently, limited beam intensities do not allow to perform systematic studies directly in the region of SHE and heavy actinides with picobarn and nanobarn cross sections, respectively. However, product nuclei with atomic number between 80 and 90 are sufficiently heavy to provide a solid basis for a first study. In addition, for a number of these elements fast and highly efficient chemical separation and detection methods are at hand.

The system $_{18}$Ar on $_{62}$Sm is a well studied heavy-ion reaction[2]. ^{40}Ar was used as a projectile while target nuclei varied. The wide span of Sm nuclides ranging from ^{144}Sm (on-shell, β_2=0.00, T=10) over ^{148}Sm (off-shell, β_2=0.16, T=12) to ^{154}Sm (off-shell, β_2=0.27, T=15) provided the basis to study, e.g., the effect of static nuclear deformation and of dynamic effects on the fusion cross section. We[*] opted for this projectile-target-Z combination to extend these studies to probe the neutron excess in radioactive Ar projectiles - up to ^{44}Ar – on the evaporation residue cross section at near barrier energies. While ^{42}Ar and ^{144}Sm have a similar neutron-excess of about 1.32 the N/Z-ratios for the combination ^{36}Ar on ^{148}Sm are 1.00 and 1.39, and for ^{44}Ar on ^{144}Sm they are 1.44 and 1.32, respectively. It is noteworthy to mention that for the latter system the neutron excess of the projectile exceeds the one of the target. A comparison of results from the spherical, n-rich nuclei ^{44}Ar (off-shell, N/Z=1.44) and ^{48}Ca (on-shell, N/Z=1.40) can yield information on the influence of shell effects. An important aspect in the evaluation of the results will be the comparison with calculated cross sections. Based on known experimental data such calculations were performed for ^{44}Ar projectiles using a modified HIVAP code[3], see Fig.1.

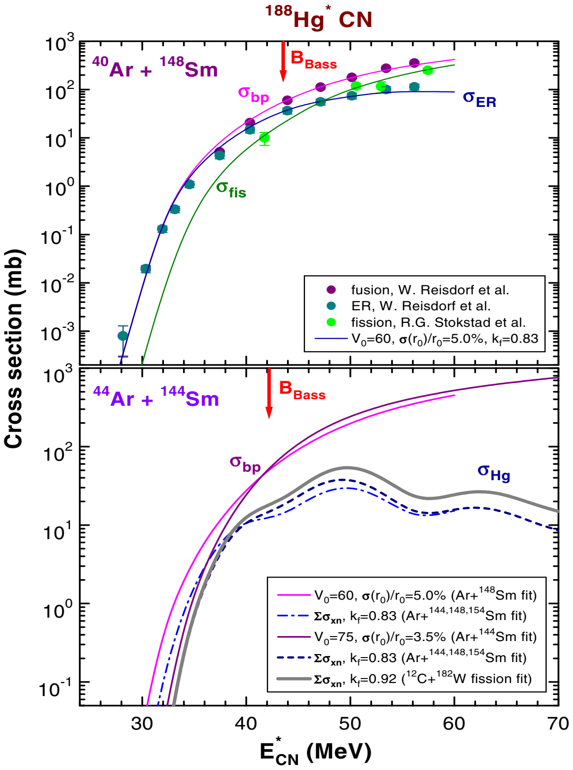

Fig. 1. HIVAP calculations of the ^{44}Ar+^{144}Sm reaction in comparison with ^{40}Ar+^{148}Sm reaction.

Most comfortably, Hg, the complete-fusion n-evaporation product in this reaction, is chemically well studied, mainly as the lighter homologue of element 112. Highly efficient

---

[*] GSI-Mainz-München-IPN-Orsay-GANIL-FLNR collaboration

separation and detection techniques are at hand to identify individual nuclei[4].

To begin our experimental program aiming finally at using n-rich Ar projectiles we selected the ^{36}Ar(^{148}Sm; xn) reaction as a first experiment to span a very large range of target-projectile combinations. Ar^{+7} beams from the UNILAC with energies of 7.38 and 7.16 MeV/u, respectively, irradiated a thin ^{148}Sm target (250 µg/cm^2, ≥ 95% ^{148}Sm) on 3µm Ti-backing mounted in X1. Ti foils in thickness of 2, 3, 4, 5, 6, 7, 8 µm served as degraders to reduce the beam energy. Cross sections were measured at energies of 135, 150, 155, 160, 165, 170, 176 and 190 MeV. These energies are uncertain within about 2%. All recoils were thermalized in helium gas and volatile products were transported in the gas flow (v=1.84 l/min) to the detector setup. The detector consisted of 4 pairs of PIPS detectors (2x2 cm) in series. The distance between top and bottom arrays was about 1 mm. The detection efficiency for alpha decay from species adsorbed at the detector surface activity was ≈ 80%. Hg isotopes produced as fusion-evaporation residues have a high volatility and were transported to the detector with a high efficiency. The isotopes ^{179,180,181,182}Hg were detected. Cross sections for these isotopes, evaluated from the measured α-spectra, are compared with cross sections theoretically predicted by R. Sagaidak, see Fig 2. Low statistics limited the results for the 2n and 5n channels. The experimental data are typically uncertain by a factor of 2.

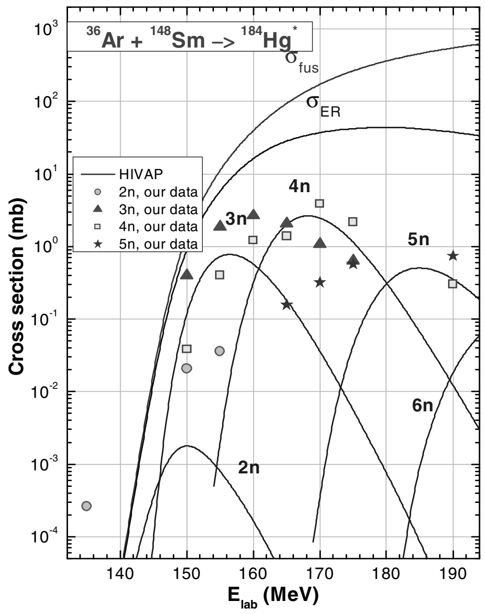

Fig. 2. Measured and calculated cross sections.

[1] Yu. Ts. Oganessian et al. Contribution at TAN'03 Conference, November 16-20, 2003, Napa Valley, USA.

[2] R.G. Stokstadt et al., *Z. Phys.* ***A 295*** (1980) 269; W. Reisdorf et al., *Phys. Rev. Lett* ***49*** (1982); W. Reisdorf et al., *Nucl. Phys.* ***A438*** (1985) 212.

[3] R. Sagaidak et al. Preprint JINR E7-2003-149, 2003, Dubna, Russia, *Phys. Rev. C* in print.

[4] A. Yakushev et al. *Radiochim. Acta* ***91*** (2003) 433.