Observations from evaporation residue cross sections in ^{45}Sc- and ^{44}Ca-induced reactions

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Recent measurements of evaporation residue (EvR) cross sections [1-3] for nuclei near the N = 126 shell have emphasized the importance of collective enhancements to the level density (CELD) for spherical ground-state nuclei and may have relevance for new superheavy element (SHE) synthesis. The study of ^{45}Sc-induced reactions on lanthanide targets [3] revealed that proton evaporation competed effectively with neutron evaporation from the compound nuclei (CN) that were produced. The *xn* cross sections of ^{45}Sc-induced reactions were also three or more orders of magnitude smaller than cross sections of ^{48}Ca-induced reactions on the same targets due to the relative neutron deficiency of ^{45}Sc.

In the last year, we bombarded ^{156,157}Gd targets with ^{45}Sc projectiles and ^{158}Gd, ^{159}Tb, and ^{162}Dy targets with ^{44}Ca projectiles as part of a systematic study to produce CN near the N = 126 shell. The beams of $^{45}Sc^{6+}$ and $^{44}Ca^{6+}$ were provided from the K500 cyclotron, and the unreacted beam and other unwanted reaction products were separated using the Momentum Achromat Recoil Spectrometer (MARS) [4]. Full experimental details are given in Refs. [1, 5].

Combined with previous results, reactions of ^{45}Sc + $^{156\text{-}158,\,160}$Gd have now been studied and 4*n* cross sections are shown in Fig. 1. As expected, the 4*n* cross sections decrease as the neutron number in the target decreases. As the CN become more neutron-deficient, the fission

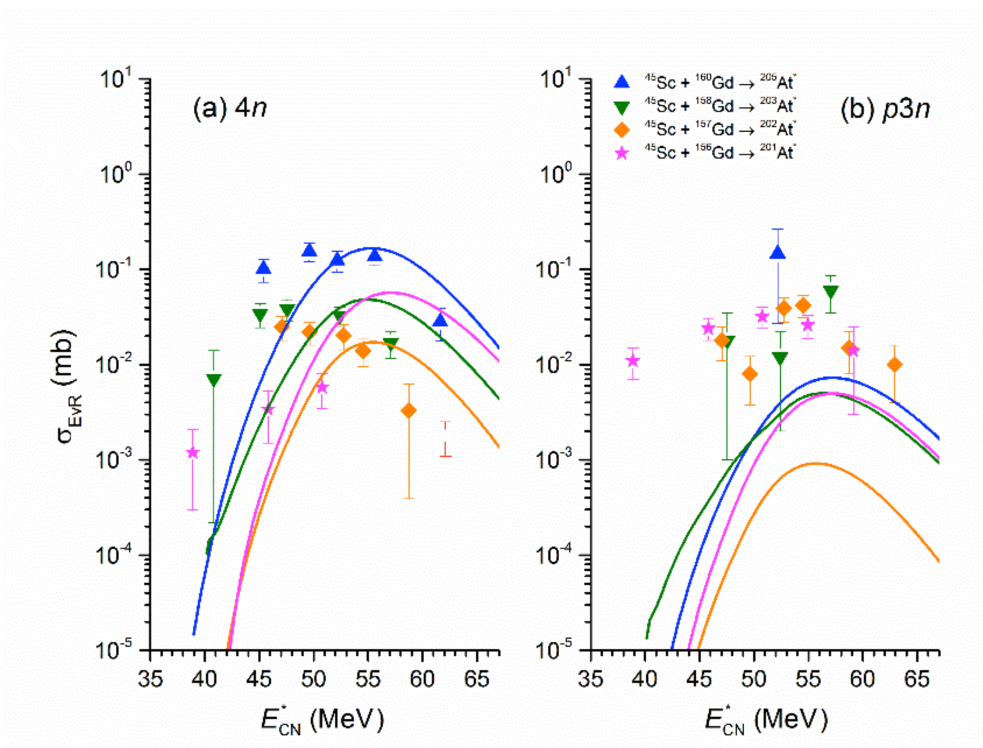

FIG. 1. (a) 4*n* and (b) *p*3*n* cross sections for ^{45}Sc-induced reactions on $^{156\text{-}158,\,160}$Gd targets. Symbols indicate experimental data and solid lines indicate theoretical calculations.

barriers decrease and the neutron binding energies increase, leading to a higher probability of fission. ^{44}Ca is of interest because it is only one proton removed from ^{45}Sc (both are N = 24 nuclei). Cross sections for the reactions of ^{44}Ca on lanthanide targets are approximately two orders of magnitude larger than for reactions of ^{45}Sc on the same targets as shown in Fig. 2. The *pxn* cross sections in the ^{44}Ca-induced reactions are also larger than in the ^{45}Sc-induced reactions. This emphasizes the role of the extra proton in ^{45}Sc in creating much more fissile CN which have low survival probabilities. A simple theoretical model based on Ref. [6] was developed, and the inclusion of CELD was necessary to reproduce the experimental data. This may have implications for producing SHEs near the predicted N = 184 spherical closed shell, as CELD may negate any possible enhancement to the *xn* cross section as a result of producing CN on this shell.

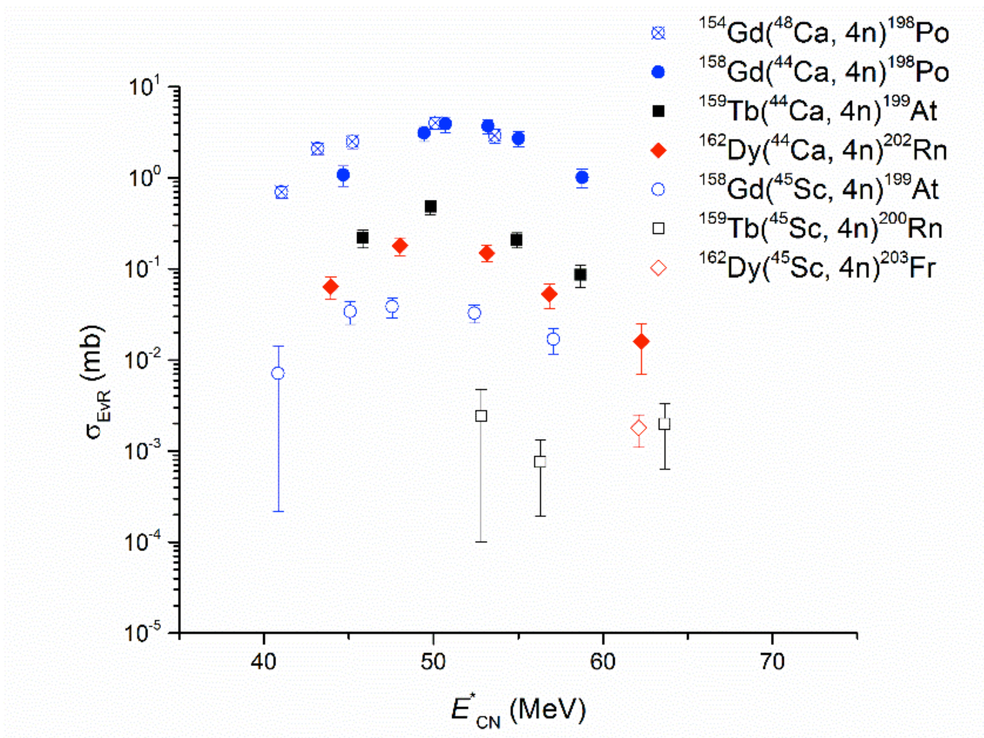

FIG. 2. Comparison of 4*n* cross sections in ^{44}Ca-induced reactions (solid points) and ^{45}Sc-induced reactions (open points) on ^{158}Gd, ^{159}Tb, and ^{162}Dy targets. The cross-bombardment reactions ^{48}Ca+^{154}Gd (circles with diagonal lines) and ^{44}Ca + ^{158}Gd (solid circles) are very similar.

Two reactions with ^{44}Ca projectiles were cross bombardments for reactions that had been previously studied using either ^{48}Ca or ^{45}Sc projectiles. Cross sections for the 4*n* EvR of the ^{48}Ca + ^{154}Gd and ^{44}Ca + ^{158}Gd reactions which produced the ^{202}Po CN are very similar (see Fig. 2). However, the maximum 4*n* EvR cross section of the ^{44}Ca + ^{159}Tb reaction which produced the ^{203}At CN is approximately an order of magnitude larger than in the ^{45}Sc +^{158}Sc reaction which produced the same CN. Some of this discrepancy should be accounted for by differences in the fusion probability, but we cannot rule out other effects such as pre-equilibrium emission playing a role [7].

These data demonstrate that the production of neutron-deficient heavy nuclei using ^{44}Ca and ^{45}Sc projectiles is relatively difficult compared to similar reactions using ^{48}Ca projectiles reacting with the same targets.

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