Structure and surrogates from STARS at Texas A&M

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During the year the Richmond group continued our active involvement at TAMU. Highlights include two weeklong STARLITER experiments, in May and October. These focused on the low/medium spin structures of of shape-transitional rare-earth nuclei, Gd and Sm with N ~ 90, from the ground state up to and well into the bound quasi-continuum, and on a first attempt to investigate the structure of light Cd nuclei of importance to the astrophysical p-process. Our latest surrogate cross section measurement, ^{236,237}Pu(n,f), has been submitted for publication.

The P.I., two postdoctoral fellows, two graduate students (collaborative with the University of Surrey UK) and four Richmond undergraduate students participated in these experiments as well as our collaborators from LLNL, ORNL and the University of Surrey. Visiting and working at the TAMU Cyclotron Facility is an enormously beneficial experience for all of these young scientists but is particularly so for the undergraduates. Preliminary results from these experiments have already been presented at the Annual SSAP Symposium in Washington DC in February and via three talks at the 2013 DNP meeting in Newport News, including one from an undergraduate student. An abstract has been accepted for a poster presentation at Vancouver for Nuclear Structure 2014 in Vancouver BC.

Our workshop apparatus at TAMU is the STARLITER array. STARLITER, developed and commissioned by our LLNL colleagues, consists of a highly segmented Si detector array (STARs, the Silicon Telescope Array for Reaction studies) to detect light charged-particle and fission fragments coupled to the 5-6 Clover-Ge detectors of the LITER (LIvermore TExas Richmond) array. Typical efficiencies are ~20% for light charged particles, ~30% for fission fragments and ~5% (200 keV) and ~1.5% (1.3 MeV) for γ-rays.

Our surrogate reaction program aims to test the efficacy of and to exploit the surrogate reaction technique to extract (n,f) and (n,xnγ) cross sections for unstable nuclei. Direct measurements of such cross sections are difficult or impossible for short-lived species. The surrogate reaction produces the same 'compound' system as the neutron induced reaction but using a stable beam and target combination. A measurement of the decay probabilities and a calculation of the formation probability yields the cross section of interest: assuming the system is equilibrated and that the spin/parity/excitation energy distributions are similar.

Our results for (n,f) cross sections in actinide nuclei show remarkable agreement with the evaluated databases for multiple nuclei and reactions, typically within 5-10% of the accepted values. Our latest results, ^{236,237,238}Pu(n,f) measurements based on a recent TAMU experiment, have been submitted for publication [1]. The result for ^{237,238}Pu(n,f) show good agreement with the database values. However, the surrogate cross section for ^{236}Pu(n,f) deviates significantly, in both magnitude and trend, from the ENDF values, Fig. 1. It is significant that for ^{236}Pu(n,f) there are essentially no data to guide the database values. We believe that our result is correct and points to an issue with the database.

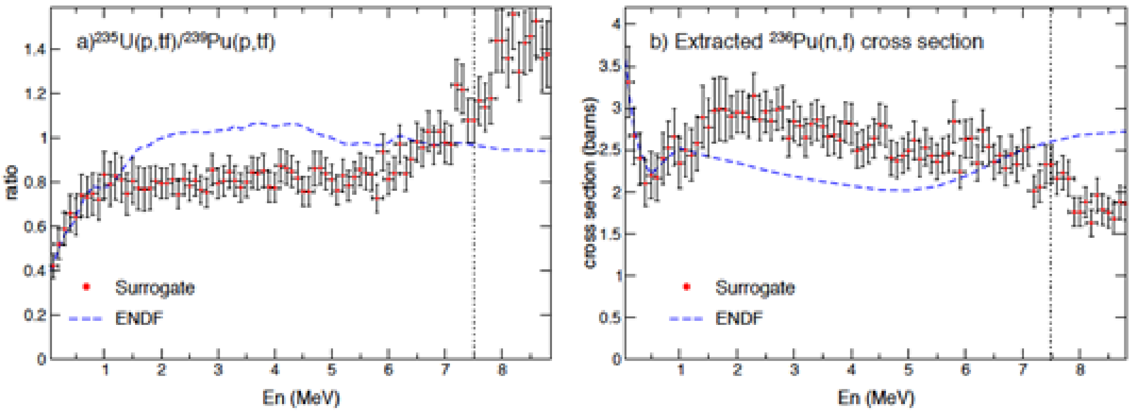

FIG. 1. Left: The data shows the ratio of ^{235}U(p,tf)/^{239}Pu(p,tf) compared to the ENDF value. Right: the extracted surrogate cross section for ^{236}Pu(n,f) compared to the ENDF value. From R.O. Hughes *et al.*, to be published

Finally, Sm and Gd nuclei with N ~90 are know to undergo a rapid shape change from near spherical (N =88) to well deformed (N = 92) and are an interesting testing ground for a variety of collective models and are also of interest for surrogate (n,γ) measurements. Low / medium spin states in $^{150-154}$Sm were populated via (p,p'), (p,d) and (p,t) reactions using STARLITER at TAMU.

The data quality is excellent and analysis is well underway. Already we have observed several new levels, have begun to extract entry-spin distributions in the bound quasi-continuum, to work on extracting level densities, to have made an improved lifetime measurement of at least one long lived isomeric state (96 minute), etc. To illustrate the selectivity of the data, Fig. 2 shows our preliminary

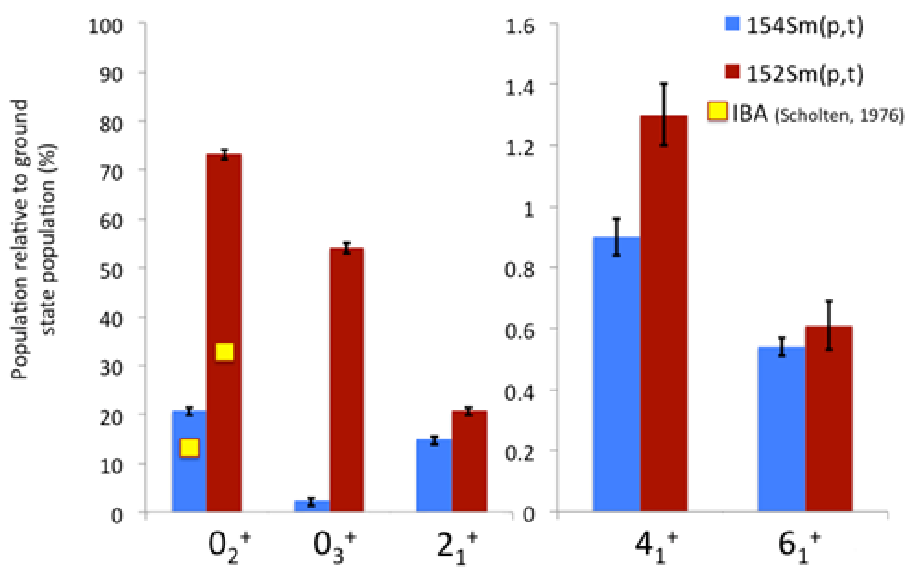

FIG. 2. (Preliminary) Measured population probability, relative to the ground state, for selected levels in ^{152,154}Sm following the (p,t) reaction. Our data are compared to the calculations of Scholten and lachello, Annals of Physics, **115**, 325 (1978).

measurements of the direct population cross section for just a few states in the yrast band and the first two excited 0^+ states, in ^{152,154}Sm. Note the dramatic difference in the relative population of the 0_3^+ level (factor of ~25) and the relatively poor agreement with calculated values (from 1976). We are working with our theory colleagues from LLNL for improved and expanded calculations for these cross sections.

[1] R.O. Hughes *et al.*, submitted for publication.