An evaluation of the possible effect of tetra-neutron production on ternary fission yields

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Ternary fission of actinides occurs in the neck region between the two heaviest fission fragments and probes the state of the nucleus at scission. In a previous publication [1] we explored the ternary fission in the ^{238}Pu(nth,f) reaction. Based upon the comparisons of theoretical yields to experimental yield we concluded that the neck region could be characterized by a temperature of 1.29 MeV, a density of 6.7 x 10^{-5} fm-3 and a proton fraction 3.5 x 10^{-2}.

The possible existence of tetra-neutrons has long been postulated. The current most credible evidence of tetra-neutron formation appears to be that of Duer *et.al.* [2] who reported evidence for a resonant four neutrons state with an energy of $E4n = 2.37 \pm 0.38(\text{stat}) \pm 0.44(\text{sys})$ MeV and a width of $\Gamma = 1.75 \pm 0.22(\text{stat}) \pm 0.30(\text{sys})$ MeV. The role that such a tetra-neutron could play in neutron star matter has been addressed in Pais *et al.* [3]. Given the extreme neutron richness found for the ternary fragment region in fission it is natural to ask whether the production of tetra-neutrons might exist and be reflected in the ternary fragment yields. We are presently carrying out exploratory calculations using the techniques described in Refs [1,3].

In Fig. 1 we present yield ratios comparing yields calculated for the ternary fission neck matter with and without inclusion of the tetra-neutron characterized by the Duer *et al.* parameters. Very clear effects are seen indicating yield modifications induced by inclusion of the tetra-neutron. However, these effects occur at densities higher than those derived in Ref. [1]. It is clear that these results are sensitive to he assumed parameters of the matter explored as well as those reported for the tetra-neutron. We are currently evaluating a range of temperatures, densities, proton fractions and tetra-neutron binding energies to understand under which conditions the effects of tetra-neutron production might be reflected at higher densities, temperatures and proton fractions which might be accessible in the laboratory, e.g, in the neck regions of deep inelastic collisions.

[1] J.B. Natowitz *et al.*, Phys. Rev. C **107**, 014618 (2023).
[2] H. Pais *et al.*, Astron.& Astrophys. **679**, A113 (2023).
[3] M. Duer et al., Nature **606**, 678 (2022).

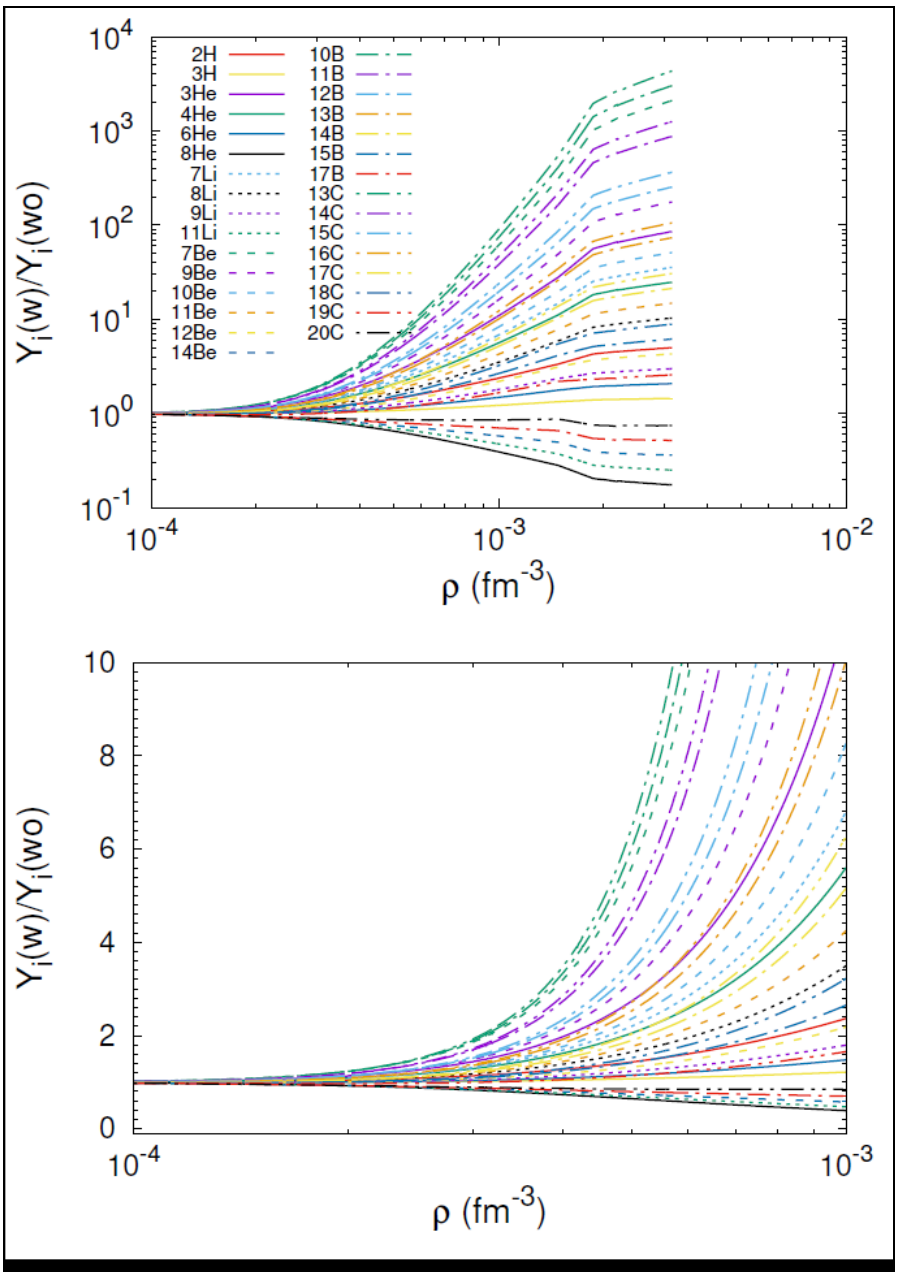

FIG.1. Yield ratios for ternary fission fragments observedin the reaction ^{238}Pu(nth,f). Ratios of yields caculated with and without inclusion of tetra-neutrons (see text) are shown. Top-full results. Bottom – expanded scale.