^{170,174,176}Yb+^{40}Ar fusion-induced fission reactions studies with ENCORE

E. Lopez-Saavedra,[1,*] S. Almaraz-Calderon,[1,†] B.W. Asher,[1] A.B. Morelock,[1] J.F. Perello,[1] A. Hood,[2] A. Saastamoinen,[2] and B.T. Roeder[2]

[1] *Department of Physics Florida State University Tallahassee Florida 32306*

[2] *Cyclotron Institute Texas A&M University College Station Texas 77843*

Evidence of rapid-neutron capture process (r process) nucleosynthesis in binary neutron star mergers via multi- wavelength observations of kilonova emission and gravitational waves has generated great excitement in the scientific community [1-2]. The reliable determination and theoretical prediction of nuclear properties like: fission barriers, fission fragment distributions, as well as the balance between the neutron separation energy and fission-barrier heights, are decisive for determining the nature of the termination of stellar nucleosynthesis in the r process. The path of the r process proceeds through very neutron-rich nuclei that cannot (yet) be studied experimentally. Therefore, experimental investigations are needed to validate the theoretical predictions and provide benchmark information in order to reliably extrapolate theoretical calculations.

A study of the fusion-induced fission excitation functions of the ^{170,174,176}Yb +^{40}Ar systems was carried out at the Cyclotron Institute at Texas A&M University. Fission in the compound nuclei ^{210,214,216}Ra, allowed to study fission excitation functions around the neutron shell closure N = 126. These measurements were performed using beams of ^{170,174,176}Yb at E = 7 MeV/u from MARS and the ENCORE active-target detector [3] filled with 40Ar gas at a pressure of 90 Torr.

ENCORE is an ionization chamber operated in an active target mode where the gas in the detector serves at the same time as target and counting gas. The segmentation in the anode strips allowed for a measurement of a large portion of the fusion-induced fission excitation function using a single beam energy. The schematics of ENCORE is shown in Fig.1.

Fission fragments from the ^{170,174,176}Yb +^{40}Ar → ^{210,214,216}Ra reactions were measured in the energy range E*lab* = 1000 - 650 MeV. The experimental data was compared with simulations and events were identified by their energy loss signals (traces) in ENCORE. A typical fusion-induced fission trace happening in strip 6 of the detector is shown in Fig. 2. The fission event (blue line) is characterized by a beam-like trace from strip 0 to strip 6, followed by a sudden jump in energy loss (strips 7 - 9), and a rapid fall in the energy loss of the trace reaching a minimum in strip 13. The fission event is confirmed by the two large fragments measured in each side of the detector (yellow and green lines) in strips 7 - 12.

* elopezsaavedra@fsu.edu

† salmarazcalderon@fsu.edu

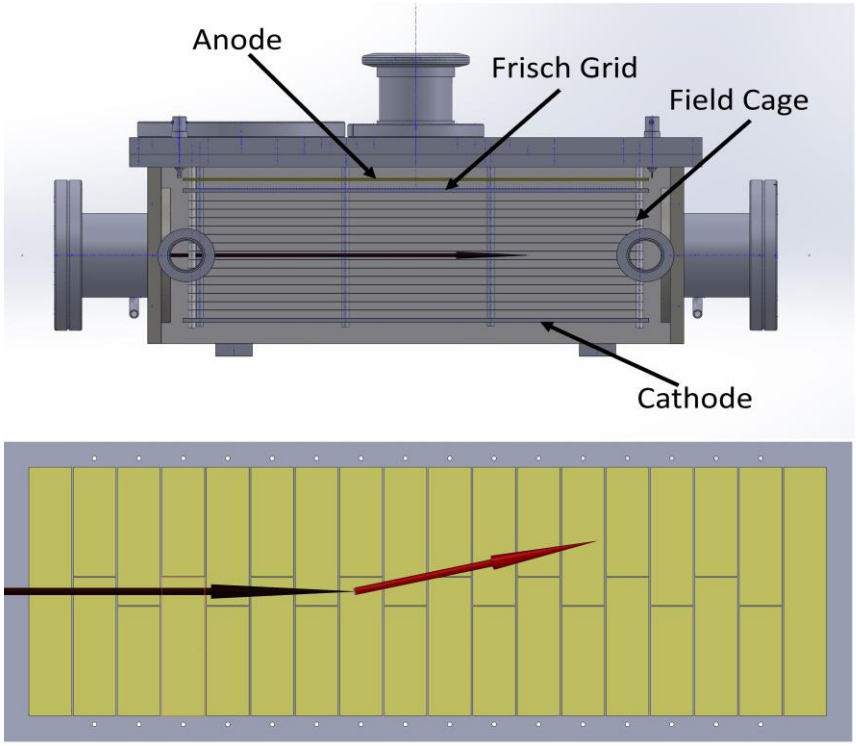

Fig. 1. Schematics of the ENCORE detector (upper figure) and the segmented anode (lower figure). The arrows indicate a reaction happening in strip 6.

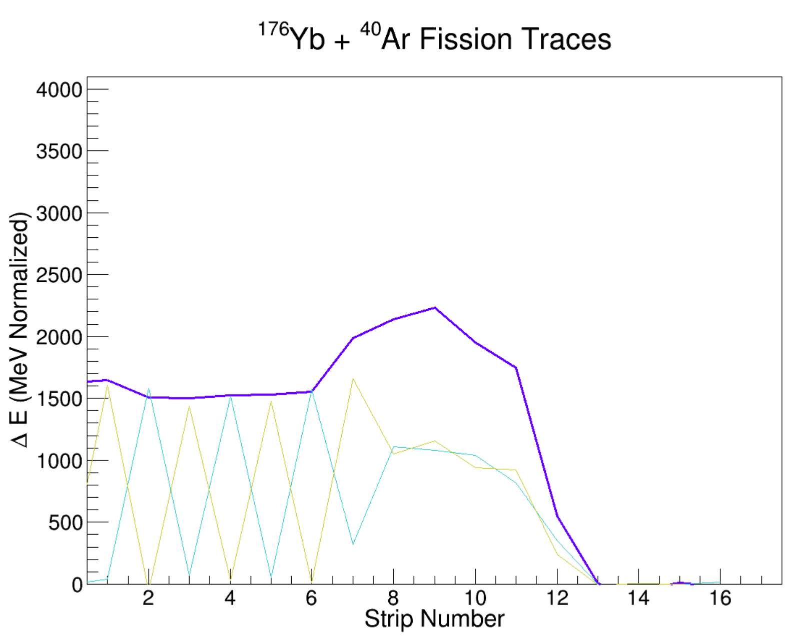

Fig. 2. Typical fusion-induced fission trace measured in strip 6 with ENCORE in the present experiment. The fission event is identified by its energy loss as it travels through the detector.

Preliminary results are shown in Fig.3, where the obtained excitation function for the ^{174}Yb +^{40}Ar→^{214}Ra system is compared with a previous measurement by H.-G. Clerc *et al.*[4], showing good agreement between data sets. The analysis is ongoing for the ^{170,176}Yb +^{40}Ar→^{210,216}Ra systems.

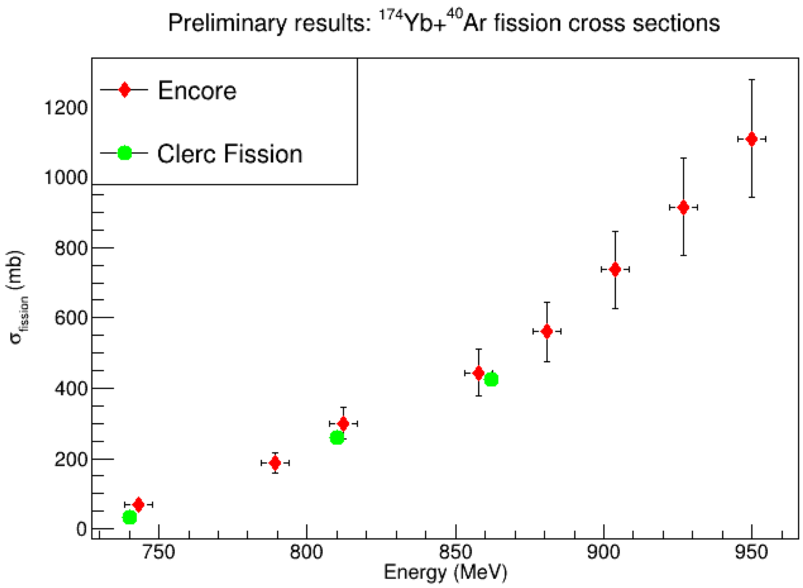

Fig. 3. Preliminary experimental cross section of fusion-induced fission measured with ENCORE for the ^{174}Yb+^{40}Ar→^{214}Ra system as a function of beam energy, in comparison with values from Ref. [4].

Results from this experiment will be used to study the evolution of fission-barrier heights, a key component in r-process network calculations. By studying the N = 126 shell closure reached with stable systems, we will benchmark our approach and validate theoretical predictions. Our technique will then be used with FRIB beams to study the evolution of fission-barrier heights around N = 126 and N =182 with exotic beams, where barrier heights are expected to rise, greatly influencing the path of the r-process [5].

[1] P. Möller, A.J. Sierk, T. Ichikawa, A. Iwamoto, and M. Mumpower, Phys. Rev. C **91**, 024310 (2015).

[2] N. Vassh, R. Vogt, R. Surman, J. Randrup, T. M. Sprouse, M. R. Mumpower, P. Jaffke, D. Shaw, E. M. Holmbeck, Y. Zhu, and G. C. McLaughlin, J. Phys. G **46**, 065202 (2019).

[3] B. Asher, S. Almaraz-Calderon, L. Baby, N. Gerken, E. Lopez-Saavedra, A. Morelock, and J. Perello, Nucl. Instrum Methods Phys. Res. **A1014**, 165724 (2021).

[4] H.-G. Clerc, J. Keller, C.-C. Sahm, K.-H. Schmidt, H. Schulte, and D. Vermeulen, Nucl. Phys. **A419**, 571 (1984).

[5] K.T. Lesko, W. Henning, K.E. Rehm, G. Rosner, J.P. Schiffer, G.S.F. Stephans, B. Zeidman, and W. S. Freeman, Phys. Rev. C **34**, 2155 (1986).