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SUPPLYING ACCURATE NUCLEAR DATA FOR ENERGY AND NON-ENERGY APPLICATIONS (SANDA)

WP 2 NEW NUCLEAR DATA MEASUREMENTS FOR ENERGY AND NON-ENERGY APPLICATIONS

MILESTONE 2.3

REPORT ON THE COMPLETION OF THE MEASUREMENTS WITH FALSTAFF AT NFS

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The FALSTAFF project [1,2] aims to provide highly constraining data to improve significantly the description of the fission process. The goal is to measure fission fragment pre- and post-neutron evaporation masses, their nuclear charge and their kinetic energy in neutron-induced fission of specific actinides in the MeV range. In addition, the neutron multiplicity as a function of the fragment characteristics will be determined. In its final version, the FALSTAFF fission fragment spectrometer, developed at IRFU, is made of two arms that combine a time-of-flight device with a large ionization chamber (Fig 1). The precise measurement of the velocity and energy of the two fission fragments emitted from a fissile target placed between the two arms will allow the determination of the fragment mass before and after neutron evaporation with a resolution (σ) of about 2%.

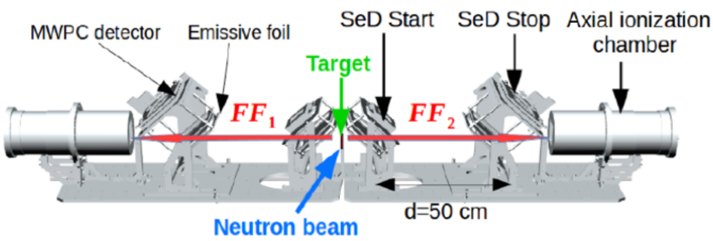


Fig. 1. Sketch of FALSTAFF spectrometer.

In the framework of the WP2, the first arm of FALSTAFF was installed at SPIRAL2/GANIL in Fall 2022 in order to study fission fragments of ^{235}U over the large incident neutron energy domain available at NFS (Experiment E814) [3].

The white neutron spectrum produced by deuterons stopped in a thick ^{9}Be target in the NFS converter room was used to perform the experiment. The ^{235}U target provided by JRC-Geel is a disk of radius 2.8 cm with a thickness of 195 µg/cm2. The beam impacts the target perpendicularly to the thin edge of the disk allowing to minimize the material crossed by the fragments. Fig. 2 shows a picture of the target on its support and an image obtained with a photostimulable phosphor plate placed at the exit of the Falstaff chamber. The target is well positioned at the center of the beam spot.

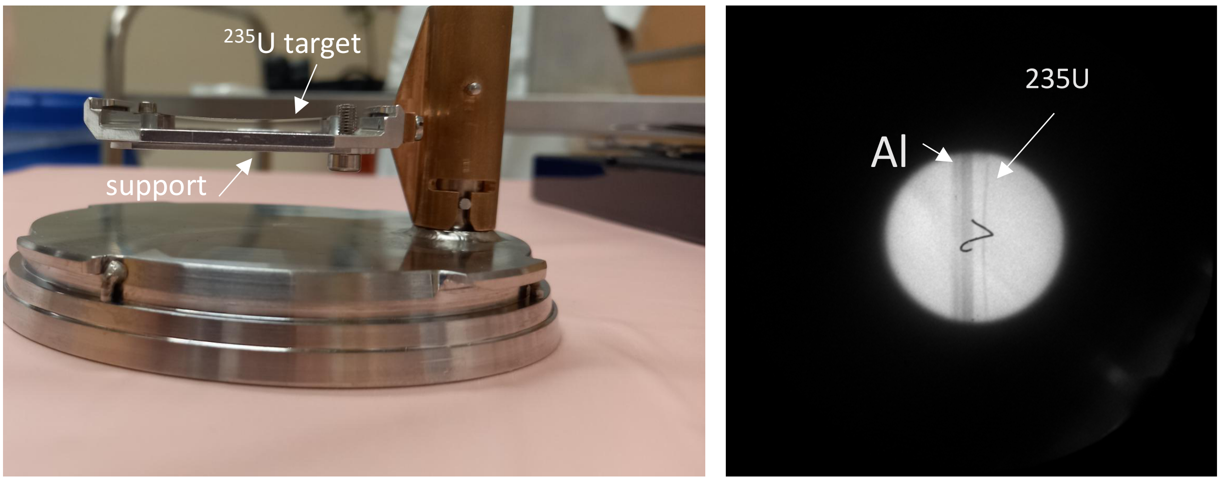


Fig. 2. Picture of the target and image registered at the exit of the FALSTAFF chamber.

In order to determine the neutron energy producing the fission detected by FALSTAFF, two LaBr3 gamma detectors have been added close to the target. They gave an absolute time reference by detecting the gamma flash produced by deuterons on Be in the converter room, allowing thus for an absolute determination, event by event, of the time of flight of the neutron which triggers the fission reaction detected in FALSTAFF. In Fig. 3, the incident neutron flux deduced from the fission counting rate in FALSTAFF is compared to the beam flux obtained with different methods. The agreement is rather good and confirms the FALSTAFF efficiency calculations (0.5 %).

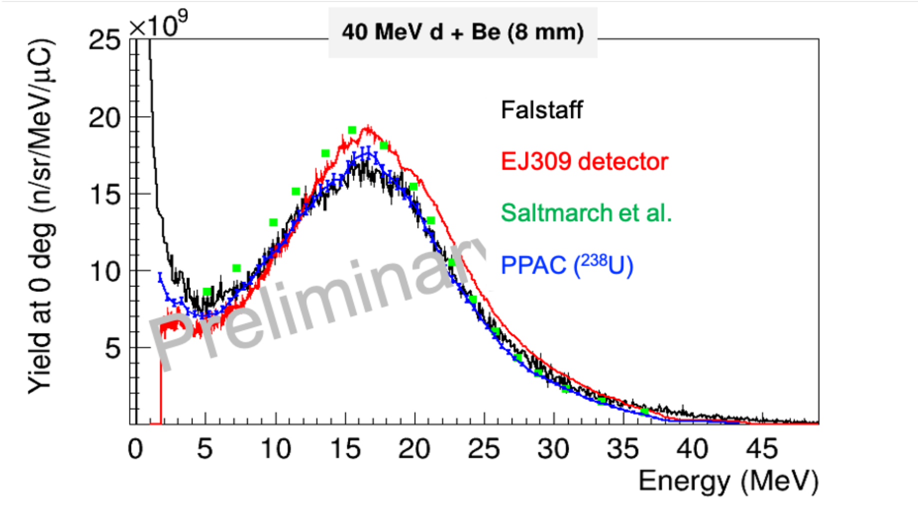
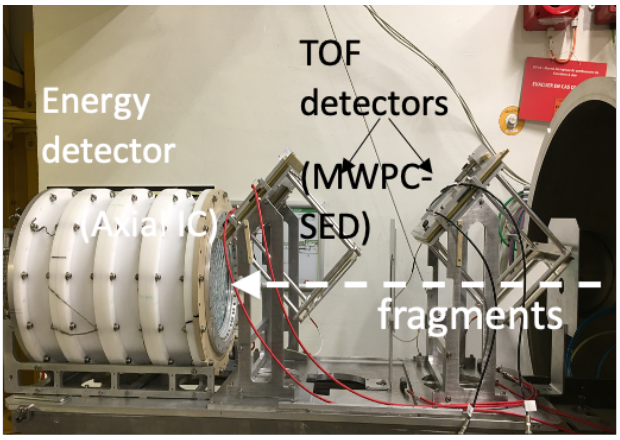


Fig. 3. Incident neutron flux at NFS for the ^{235}U experiment.

Based on time-of-flight (ToF) and residual energy technique, the FALSTAFF one-arm setup (Fig. 4) measures fission-fragment velocities and energies. The necessary timing resolution is obtained by using two secondary electron detectors (Start and Stop detectors) for the ToF measurement. This detector combination can reach the required time resolution (σ) of 150 ps and a position resolution better than 2 mm. A mask (Fig. 5, left panel) was placed between start and stop detectors and a ^{252}Cf source at the target position to measure the position resolution. The right panel of Fig. 5 shows the image from which a spatial resolution of 1.2 mm was determined.



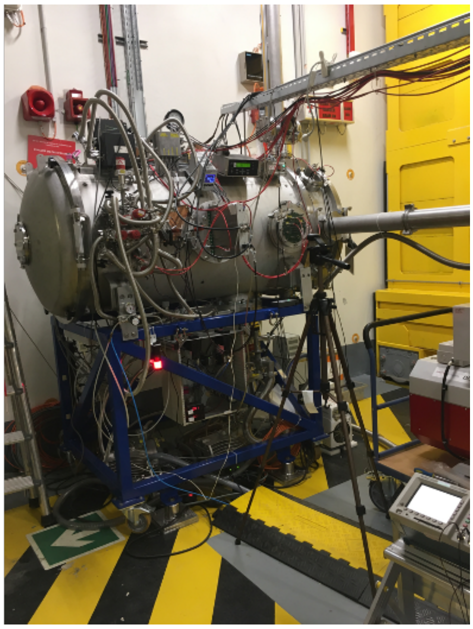


Fig.4. Picture of FALSTAFF detection (left) and installed in the NFS TOF hall (right).

An axial ionization chamber is placed behind the stop detector to measure the fragment residual energies. The choice of an axial field for the ionization chamber was motivated by the possibility to reconstruct the energy loss profile by detecting the number of electrons as a function of their arrival time on the anode. Moreover, the dead zones are minimized for this type of ionization chamber. In March 2022, this ionization chamber was placed besides the VAMOS spectrometer for an experiment [4]. It was found that the energy resolution was ~1 % which is the requested resolution. From the same experiment, encouraging results are obtained for the nuclear charge determination (not presented here).

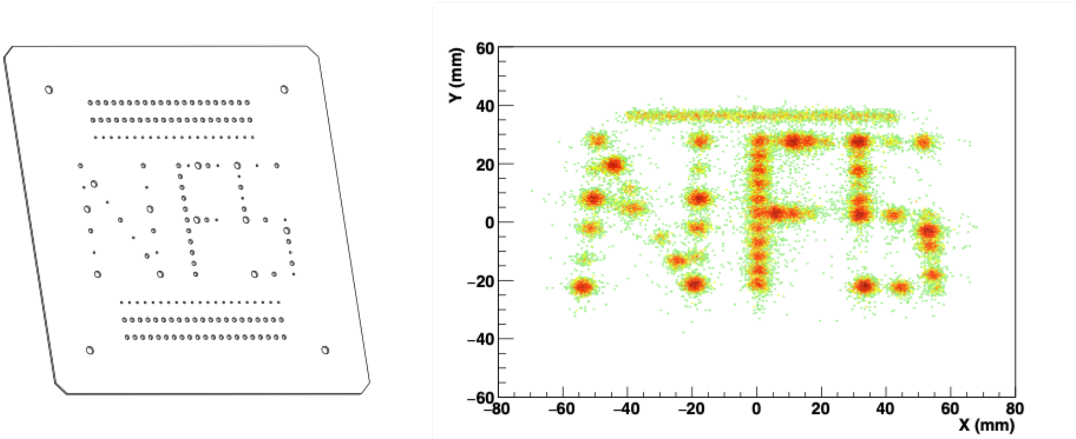


Fig. 5. Mask (left) and reconstructed positions (right) acquired with the mask and a ^{252}Cf source placed at the target position.

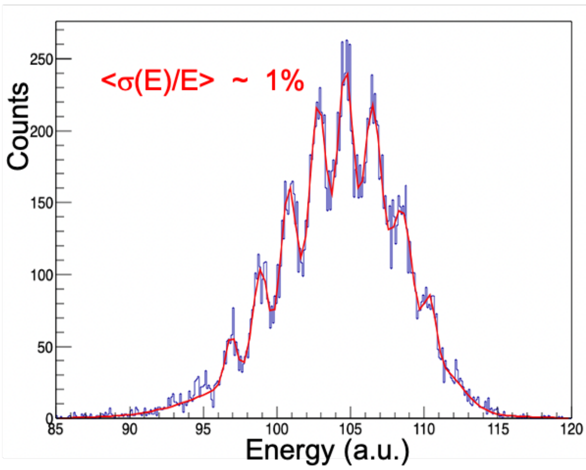


Fig. 6. Energy distribution for fragments not stopped in FALSTAFF ionization chamber (private communication).

PRELIMINARY RESULTS

Analysis of the E814 experiment is still in progress. Some observations can already be done.

The beam allocated was 11 UT while the requested one was 50 UT. Then the statistics is not as high as expected. In addition, the neutron energy distribution is different from the estimated one. The very low energy contribution was higher than those extrapolated from Saltmarsh [5] used to calculate the requested beam time.

Time, position and residual energy of fragments have been registered. Calibration procedures are almost finished. Background identification and calculation is still under study.

In Fig. 7, the preliminary velocity distributions for three different neutron energy bins are compared. One observes that the valley between peaks is filled when the neutron energy increases. This feature is known and means that structure effects decrease when the excitation energy increases. In addition, with the increase of neutron energy, the openings of different fission chances channel occur.

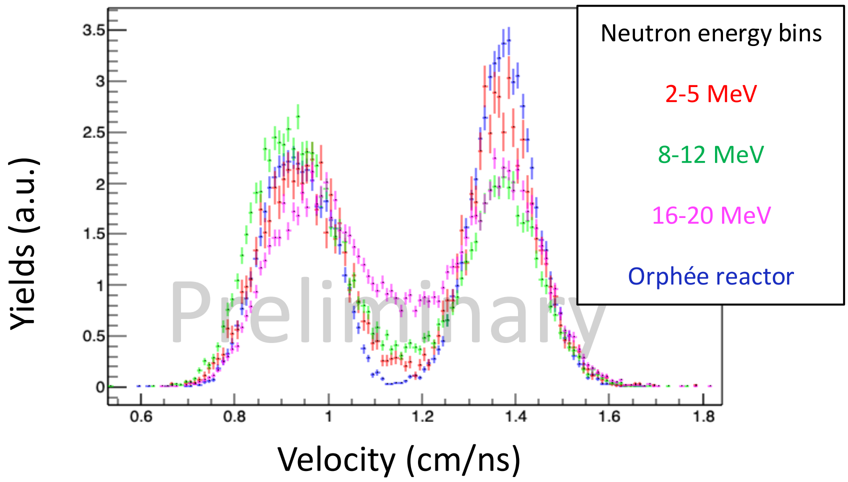


Fig. 7. ^{235}U fission fragment velocity distributions for different incident neutron energy bins at NFS and in the Orphee reactor neutron flux.

FALSTAFF was previously installed at Orphée (reactor at CEA/Saclay). The velocity distribution for this measurement is shown in blue in Fig. 7. Here again the trend is clear and is in agreement with the evolution described above.

CONCLUSION

The E814 experiment was performed at NFS in 2022 to study ^{235}U fission fragment distributions as a function of different incident neutron beam energies. The experiment setup worked properly. Preliminary results are encouraging. Unfortunately, the beam time was too small to reach the desired statistics.

The stable operation of FALSTAFF and the promising results led our hierarchy to decide to launch the construction of the second arm of the setup. It should be ready for the first experiment by the end of 2025.

References

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[2] L. Thulliez, Caractérisation des fragments de fission et développement du dispositif expérimental FALSTAFF, Ph.D. Thesis, Université Paris-Saclay, Sept. 2017.

[3] X. Ledoux et al., First beams at neutrons for science, EPJ A (2021) 57:257.

[4] D. Ramos et al., Private communication.

[5] M. J. Saltmarsh et al., NIM 145 (1977) 81-90.