Fission Spectrometer for Individual Fragments Correlated with Gamma-rays

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Abstract

Fission product yields are an important data set for improving the reliability and accuracy of many simulations, fission theory predictions and reactor design elements. The current fission product yield data sets are subject to high uncertainty outside of thermal (0.025 eV) and fusion (~14 MeV) neutron energy regions as well as some more exotic actinide targets. At the University of New Mexico (UNM) we have already fielded a fission spectrometer that uses energy-velocity (E-v) correlations for individual particles. The spectrometer consists of a heavy ion time-of- flight (TOF) module followed by an ionization chamber (IC), for velocity and kinetic energy measurements, respectively, of the ejected fission products. Our IC uses an active cathode design which allows us to determine the depth of penetration of the fragments, from which, we can extract the charge, Z, information of the products. Tagging of prompt, and quasi-prompt (>50ns) to delayed gamma-rays is implemented at the fission source and near the IC, respectively. The prompt gamma-rays detected near the source give an immediate response when a fission event takes place and can be associated with the production of an identified fragment. Gamma-ray detectors near the IC give us timing and spectra >50 ns after the fission event takes place. These can then be used in coincidence with direct product measurements from the ToF and IC to generate very clear gamma-ray spectra.

Introduction

In recent years there has been increased interested in gathering high precision fission product yield (FPY) data. FPY uncertainties are of primary importance to the results when modeling and calculating the fission product inventories at certain locations and times in a reactor's life cycle, or for other fission dependent processes. This data can determine the best practice when operating the reactor efficiently and safely, as well as handling the fuel and its safe long-term storage [Hambusch]. Correlating the A, Z and associated gamma-rays of fission products from special nuclear material would lead to faster identification times with more certainty in national security applications. In the currently used FPY data there are high relative uncertainties for even the most well-known fissioning systems. On the edges and near the valley of the FPY curve there can be uncertainties greater than 40% while even the more common masses in the peaks have as much as 10% [Pomp]. From ENDF/B-VII.1 to ENDF/B-VIII.0 there was no change in the FPY data that was used, however they expect to see an update to this data for the release of ENDF/B-VIII.1. That data currently comes from England and Rider's work, more than 30 years ago [ENDF 8]. The UNM fission spectrometer can gather important correlated data points such as velocity (v), kinetic energy (E), mass (A), charge (Z) and gamma-rays associated with a particular fission event and fragment. The data presented in this paper will be from ^{252}Cf spontaneous fission.

Mass and Z Determination

The UNM fission spectrometer, shown in figure 1, has been developed into a system that generates high precision, correlated FPY data. The ToF system uses an upstream and downstream microchannel plate (MCP) detector, each coupled with a thin carbon foil the fission fragment passes through, ejecting electrons, and an electrostatic mirror redirecting those electrons towards the MCP. Velocity is calculated using the difference between the start and stop signals generated by the fragments traveling the known distance between the timing modules. Separating the IC gas and the high vacuum ToF side is a thin SiN window. The IC consists of a negatively charged cathode with a series of guard rings descending in voltage towards a grounded Frisch grid that separates the positively charged anode [Sanami]. The IC acts as an axial time projection chamber: the active cathode timing can then be compared to the anode timing and a depth of penetration of the fragment into the IC can be calculated and from this, Z is extracted [Blakeley]. Finally, the anode pulse height is measured because it is proportional the energy deposited by the fragment.

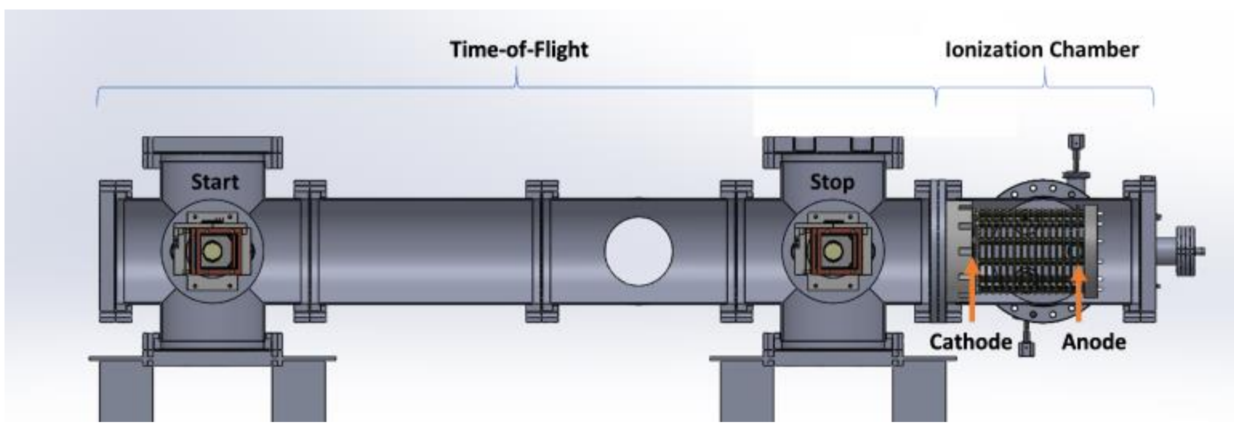

Figure 1: The UNM fission spectrometer.

Both the ToF and anode give time stamped signals into our data acquisition system (DAQ). If the signals are within the timing correlation window, it is accepted as correlated data. This is enough data to start recreating the fragment masses but correction factors, such as energy loss, must be accounted for. This makes the data more representative of the initial fission fragment. Energy is lost whenever the fission fragment interacts with a material. All fission fragments that give correlated ToF and anode signals have lost some amount of energy from the carbon in the ToF system or the SiN when entering the IC. The energy lost by ^{252}Cf fission fragments in carbon and SiN has already been characterized in Baldez 2019 [Baldez]. In figure 2 it is shown that these corrections shift our calculated mass into a reasonable range that agrees well with published FPY data, which it was not in before.

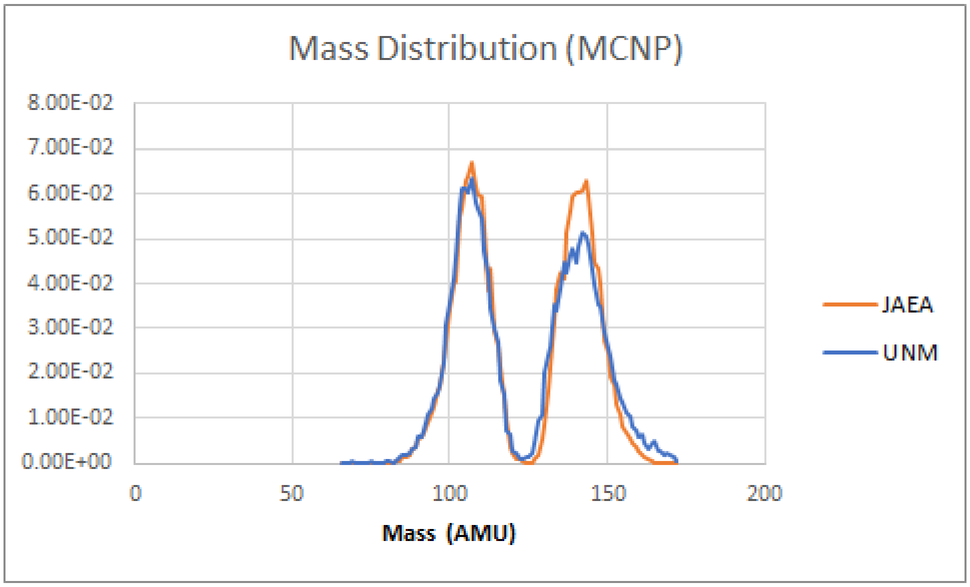

Figure 2: Mass correction and comparison to ^{252}Cf JAEA published data [JAEA].

The number of protons or Z of a fission fragment is the main contributor to the kinetic energy lost by the fragment as it interacts with materials. The ionization electrons liberated as the fragment deposits its energy, are accelerated towards the anode and will only begin to induce a pulse on the positively charged anode once past the grounded Frisch grid. The movement of the electrons away from the negatively charged cathode will also induce a pulse as soon as the fission fragment enters the IC. The time difference between the cathode and anode pulses gives us an approximation of the depth of penetration of the fragment into the IC. This can then be used to extract the correlated Z data. As of the writing of this paper there are not enough counts using the ^{252}Cf to be able to draw statistically meaningful data from but figure 3 shows a sample of previously obtained ^{235}U data.

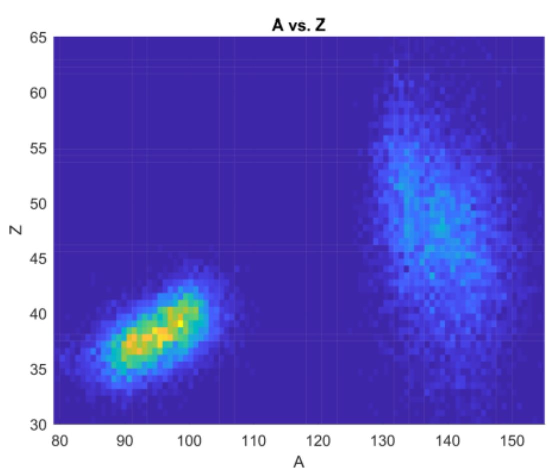

Figure 3: Z distribution of ^{235}U.

Prompt Gamma-rays from Fission Events

Along with fission fragments and neutrons, energy is emitted in the form of gamma-rays. These gamma rays can come from the fission events itself or from the fission fragment. High purity germanium detectors (HPGe) were added to the UNM fission spectrometer to detect the prompt, and quasi-prompt to delayed gamma rays that are released from the fission event. An HPGe placed near the fission source gives prompt gamma-ray spectrum associated with the fission event. Data has been gathered by a gamma-ray detector near the IC, which can detect quasi-prompt and delayed gamma rays given off by the fission fragments, this work from our group is presented by Mark Wetzel (abstract 433).

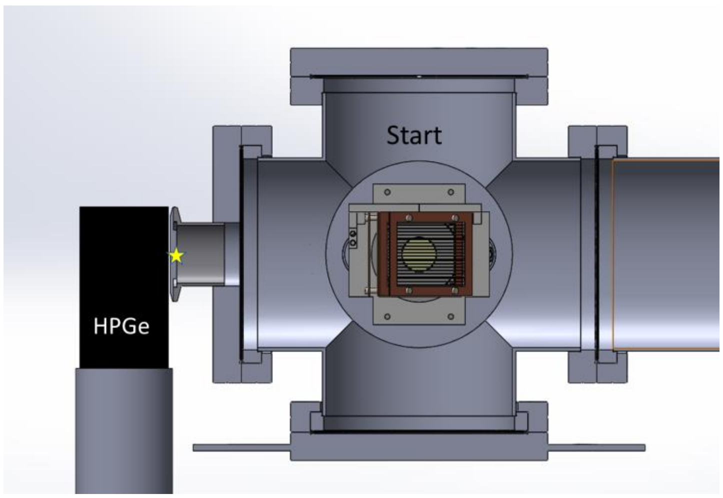

Figure 4: Prompt gamma-ray detection setup.

Not all gamma-rays detected will be from prompt fission events, the source measured is a 5 year old ^{252}Cf source, so there has been significant buildup of fission fragments which still give off gamma-rays, and so a fission coincidence gate is used. The start signal from the first MCP in the ToF system is the first signal generated by a fission fragment in our system, and is time correlated with gamma rays. Figure 5 shows the number of counts seen by the gamma-ray detector as a function of time before the start signal. This peak shows the gamma-rays from a fission event and their approximately 3 microsecond delay, most of which comes from the signal processing before they are recorded with their associated time stamps.

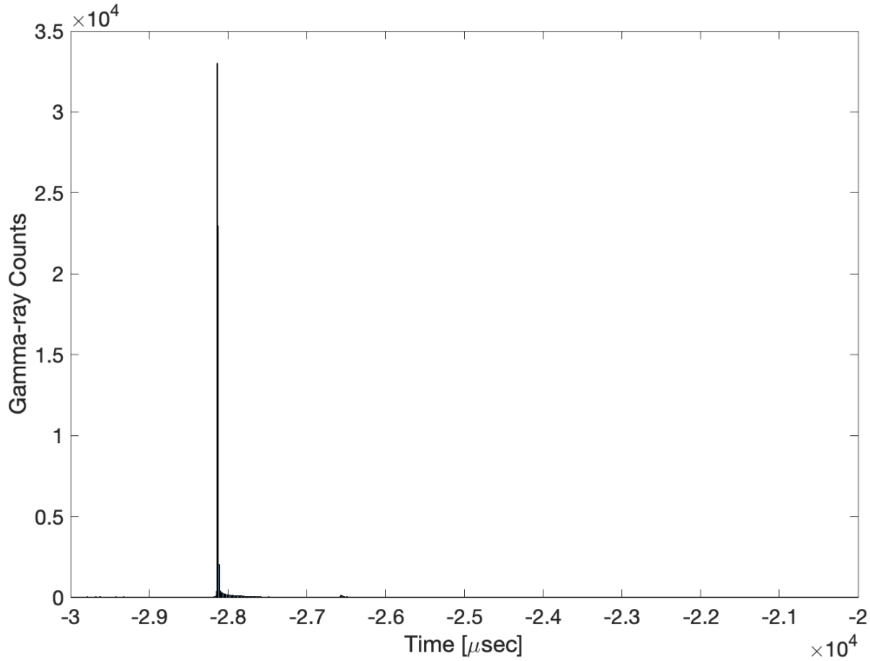

Figure 5: The number of gamma-rays as a function of time before the “start” signal.

The IC entrance window has a small solid angle from the source, so most fission fragments used as the gate will not enter the IC. Most fission gates will not produce an IC anode pulse to provide fully correlated data to extract mass, but the gating will allow measurement of prompt fission gamma-rays. Figure 6 shows the prompt energy spectrum of these gamma-rays.

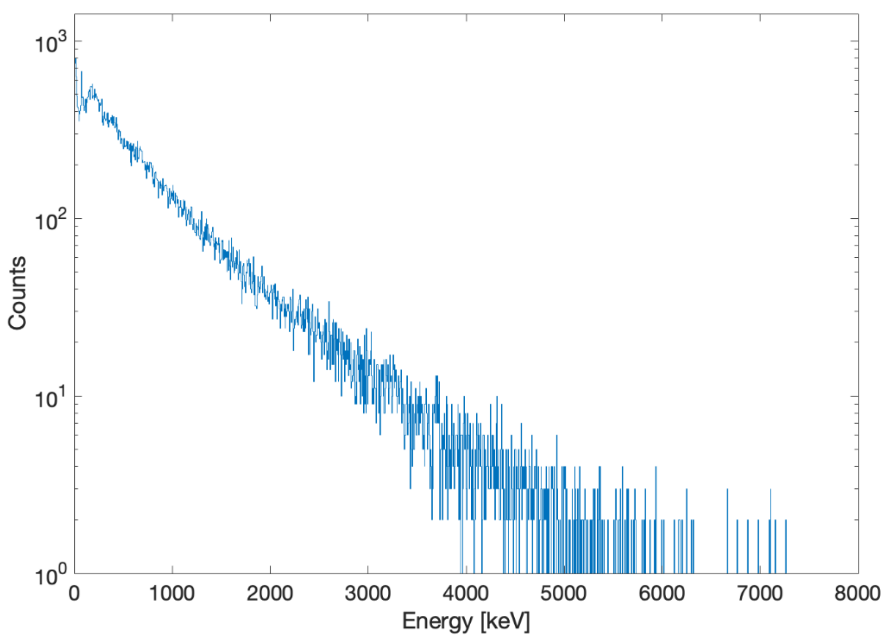

Figure 6: Prompt gamma ray energy spectrum from Cf-252.

Correlated Gamma-rays

The goal of the UNM fission fragment spectrometer is to have correlated data on v, E, A, Z and gamma-rays from individual fission fragments. Instead of associating the gamma-rays with the closest timing device, they will now be associated with the less active anode. The resulting gamma-ray spectra, shown in figure 7, is down selected to only gamma rays from fission fragments with correlated v, E and A.

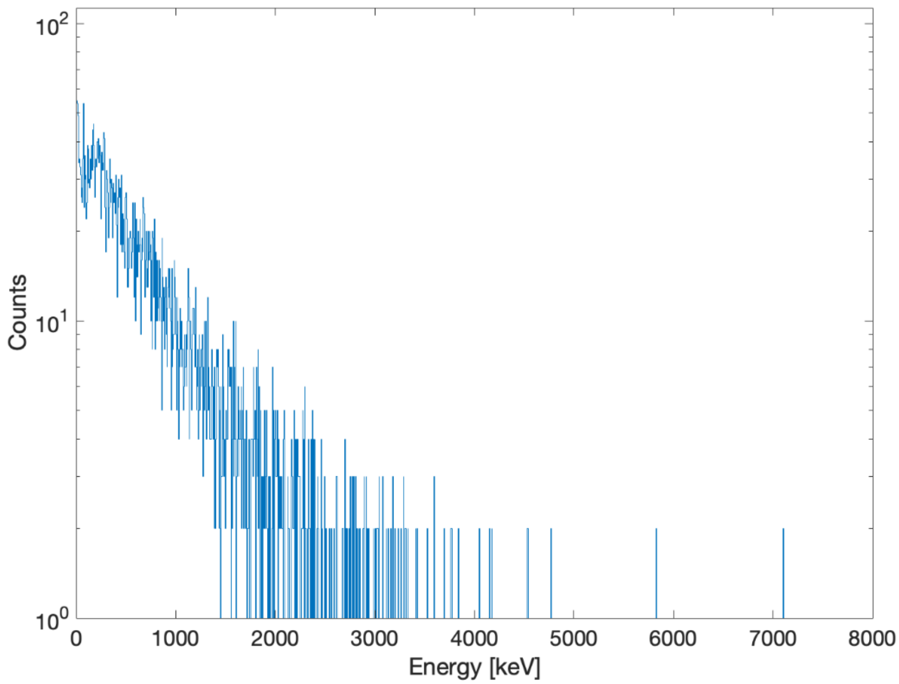

Figure 7: Gamma-ray spectra of events that have correlated v, E and mass.

It is now possible to choose a certain mass bin and look at the gamma-rays that are correlated with that mass. This makes the dataset even smaller and as of right now the counting statistics are such that large mass slices must be taken for the spectra shape to be distinguishable. Figure 8 contains two spectra, the left shows gamma-rays associated with a mass range of 108-140amu and the right shows gamma-rays associated with a mass range of 80-104amu as well as 144-170amu.

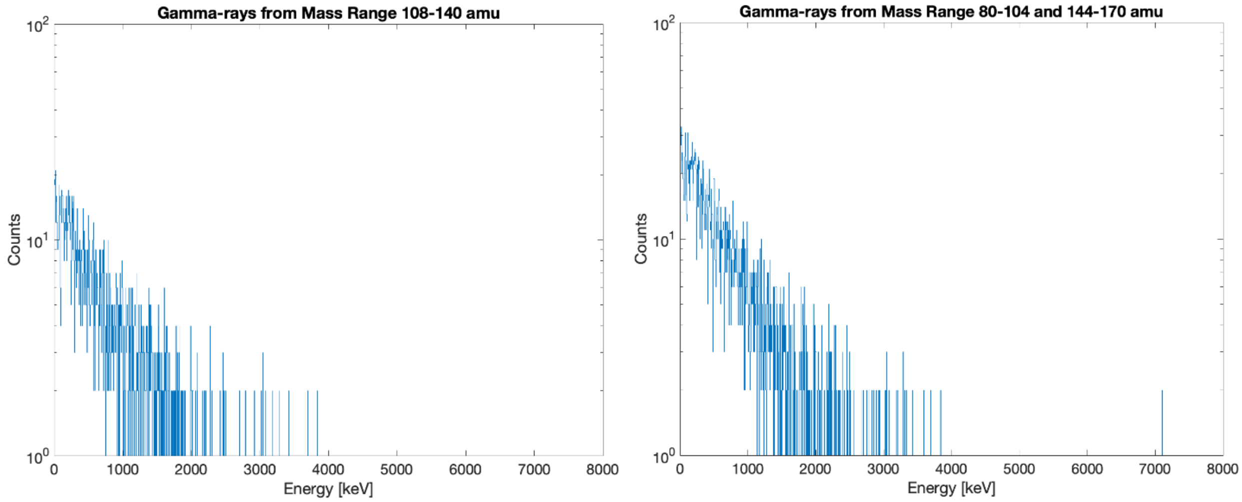

Figure 8: Gamma-rays associated with mass range 108-140amu (left) and 80-104amu and 144-170amu (right).

Future Work

The UNM fission spectrometer can gather highly precise, correlated v, E, A, Z and gamma-ray data. The UNM fission spectrometer has LANSCE beam time scheduled for 2021, where we will run with ^{239}Pu with a higher fission rate than we are measuring with ^{252}Cf. Also, at the time of writing this paper there are only four DAQ channels. The signals to record are the first MCP time pulse for fission gating, the TOF, the IC anode, the IC cathode-to-anode time difference, and gamma ray detectors, which means we were choosing between signals. We have recently repaired our eight channel digitizer which will allow us to run the full system with several HPGe detectors for higher efficiency measurements of both prompt and quasi-prompt to delayed gamma ray coincidences.

References

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