High Efficiency Fission Tagged U235 Gamma Ray Data

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Abstract

In this work we are examining gamma rays correlated with fission. In the first part, a U-235 fission target was placed inside of the Total Kinetic Energy (TKE) double Frisch-gridded ionization chamber and bombarded with neutrons at LANSCE to induce fission. The two emitted fission fragments ionize the gas in the two sides of the chamber. Electrons in the ionized gas, under an E field, generate signals on the Frisch grids and anodes. These signals can be used for identification or, in our work, for gating on fissions. A $LaBr_3$ detector was used beside the TKE chamber for gamma measurements. LANSCE provides a t_0 signal for each beam pulse, at 20 Hz, allowing us to examine gamma spectra as a function of time. We are able to use this setup to gather the energies of both fragments in binary fission simultaneously, allowing us to extract mass information to correlate with the gammas. Work was also performed on prompt gamma rays tagging on fission using a Si surface barrier detector, and finally tagging on fission using the UNM Fission Spectrometer to examine gamma rays correlated with the spectrometer ionization chamber. This data will help in many areas, including stockpile stewardship, fission theory, and nuclear safeguards.

Introduction

The University of New Mexico (UNM) Fission Spectrometer Group looked at fission tagged gamma data using a total kinetic energy (TKE) chamber using ~~Uranium~~U-235 at Los Alamos National Laboratory (LANL). While a full Fission Spectrometer run at LANSCE was planned, the TKE experiment was performed as a result of lab travel restrictions due to Covid-19 preventing us from bringing the full UNM fission spectrometer to the flight path. While the initial intent of this paper was to discuss data obtained through our TKE experiment, we will also discuss experimental results that have recently developed within the lab at UNM. These experiments include the UNM Fission Spectrometer using ~~Californium~~Cf-252, and a surface barrier detector diode setup using ~~Californium~~Cf-252

TKE Experiment

A U-235 fission target was placed inside of the Total Kinetic Energy (TKE) double Frisch gridded ionization chamber, and used in the neutron beam at the LANSCE Lujan Center. The two Frisch grids and anodes surround the fission target, Fig. 1, so that both fission fragments can be measured.

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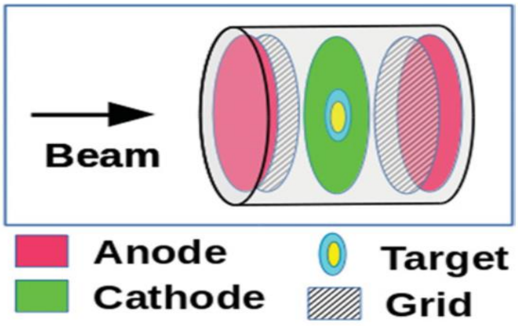

Figure 1 - Mockup Drawing of the TKE [1]

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The chamber is filled with P-10 gas and the target is bombarded with incident neutrons to induce fission. As the emitted fragments travel through the chamber, they ionize the gas proportional to each fragment's kinetic energy. Since we are measuring both fragments simultaneously, we can obtain the total kinetic energy of the fission event. The ratio of the energies of each fragment can be used to extract the masses in each pair as seen below:

$$\frac{M_1}{M_2} = \frac{E_2}{E_1}$$

We used a LaBr$_3$ detector next to the TKE chamber to measure gammas in coincidence with anode and grid events. The cathode timing is close to the fission event and so should be used for time gating the gamma rays. Additionally, LANSCE provides a t0 signal for each beam pulse, at 20 Hz that could be used as a common time stamp to correlate the data from the grids, anodes, and gamma detector. Initially, the gamma count rate within the flight path chamber was too high, over 50 kHz, and the detector needed to be shielded with borated poly and lead bricks, seen in Figure 2.

Figure 2 – Layout of the TKE Experiment. The LaBr Detector is shielded in lead and borated poly.

Since this experiment was assembled quickly between covid delays and the end of the beamtime, experimental conditions were not optimized. The cathode was firing on the noise and the rate was too high to correlate with gamma rays in a useable manner. This was a major problem because the cathode signal is the closest in time to the occurrence of fission, as the fission target is physically attached to the cathode. We were unable to correlate cathode signals with fission signals due to a high background noise of non-fission sources. In addition, to extract masses from the anode energies, energy loss corrections must be performed that rely on the shape of the grid signals. We took wave form measurements of 96 ns in length, while the length of the signals was on average about 500 ns, which did not allow for corrections for cleaner mass determination

Figure 3 - Summed Gamma Rate

A heatmap of the gammas over time after t_0 can be seen in Fig. 4. Fission is more probable with the slower neutrons, which are slightly delayed coming from the p-to-n convertor target.

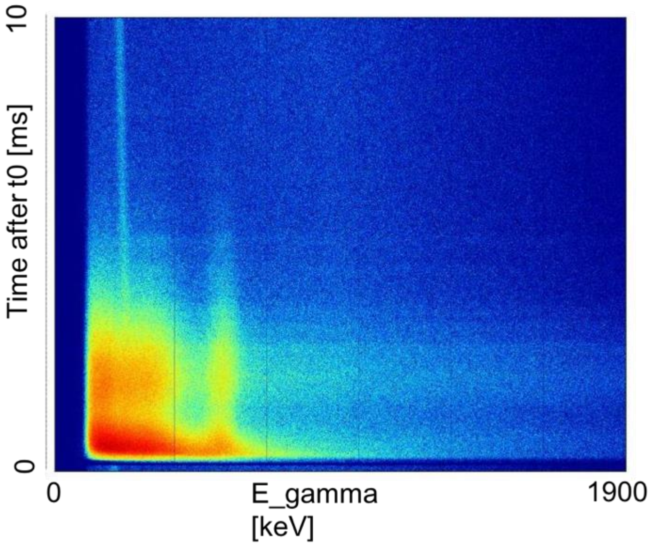

Figure 4 - Plot of gamma ray energy vs time after neutron beam pulse t0.

Mass generation was partly possible. The fission fragments lose energy as they traverse the

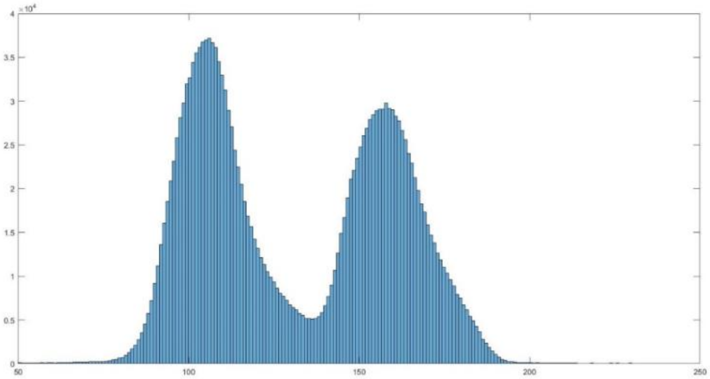

Figure 5 – Uncorrected, Rudimentary Mass Distribution

Surface Barrier Detector Experiment

This is a proof of concept experiment performed in the lab. A Cf-252 source was attached to a silicon surface barrier (SSB) and sealed against light, then placed atop a High Purity Germanium Detector (HPGe). The goal is to prove that it is possible to find a fission gamma burst from Cf-252 spontaneous fission and correlate the data between charged particle detection with the SSB and the gammas with the HPGe. The SSB showed both fission energy peaks and the alpha energy peak. Gating on the fission peaks and examining the time difference between gammas and fission we see a strong time histogram peak, Fig. 6.

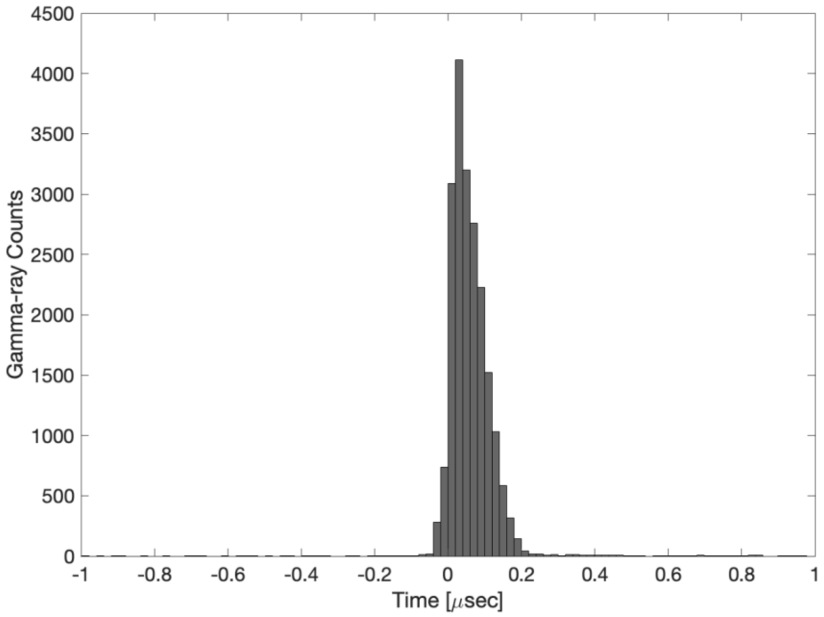

Figure 6 - SSB Detector Fission Gamma Burst

Afterwards, we made a gamma energy spectrum (in arbitrary units of channel number) within the fission timing window, seen in Fig. 7.

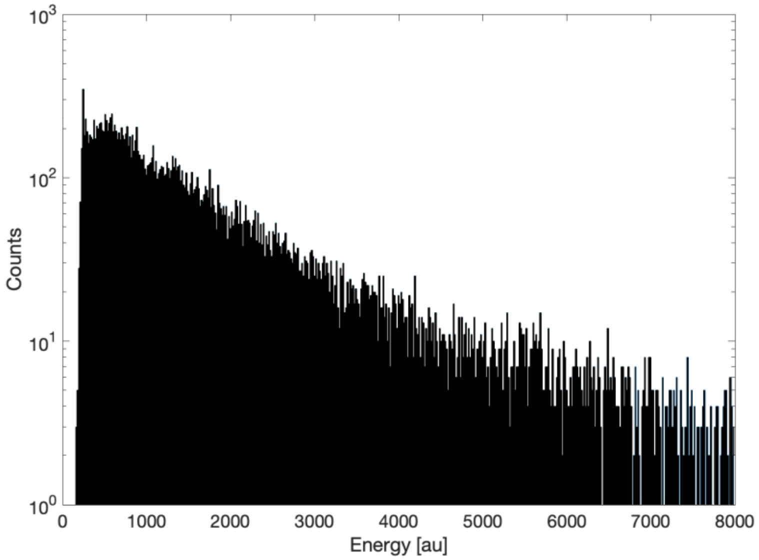

Figure 7 – SSB-Correlated Fission Gamma Spectrum

UNM Fission Spectrometer Experiment

The UNM Fission Spectrometer, seen in Fig. 8, allows us to measure fission fragments through gathering the velocity and energy of each particle. Fission fragments go through two timing modules, each with 20 μg/cm^2 carbon foils and secondary electrons are ejected as they pass through them. These electrons are reflected using electrostatic mirrors into microchannel plate (MCP) detectors. When the ejected electrons strike an MCP, a pulse is produced that is used for timing. With two timing modules you have two timestamps that can produce a time of flight, t, with a known distance between the two foils.

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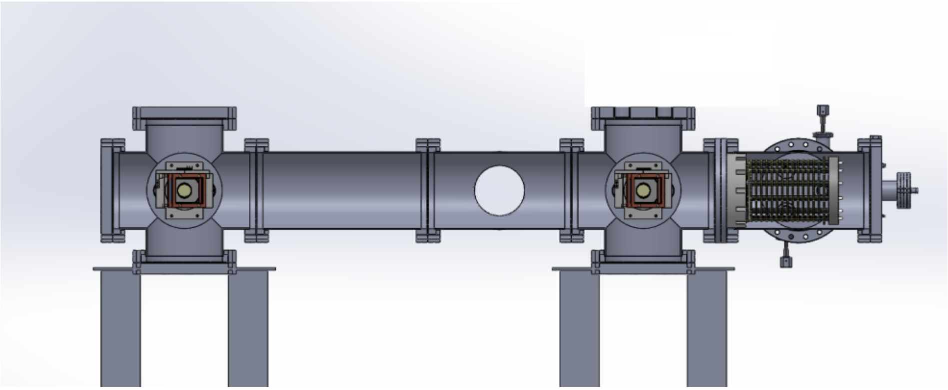

Figure 8 - CAD Design of the UNM Fission Spectrometer, showing the two mirrors and MCPs, and the ionization chamber on the far right.

Further downstream, after the second carbon foil, mirror, and MCP is the ionization chamber (IC), which is used for Z determination and can be seen in Fig. 9.

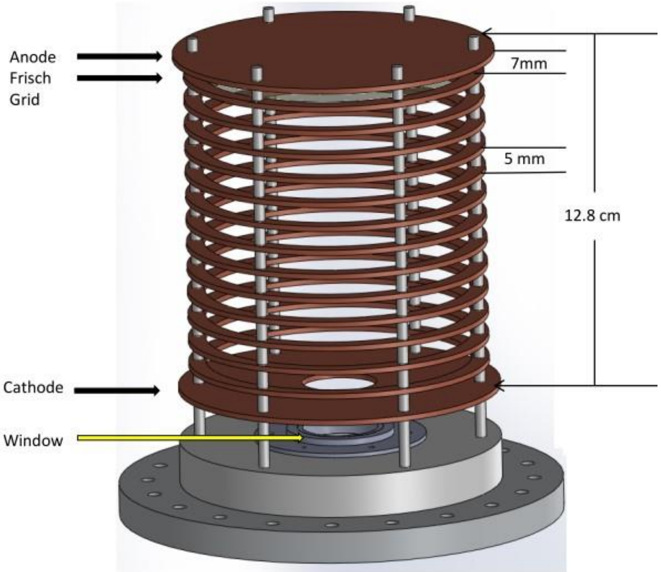

Figure 9 - Ionization Chamber Design

The entrance to the IC is blocked off by 200 nm SiN window to isolate the high vacuum from the IC. The ionization chamber is filled with isobutane gas and is comprised of a copper cathode that is connected to the aluminum housing of the SiN window, 15 copper guard rings, a gold-plated tungsten Frisch grid, and a FR4 anode. When a fission fragment enters the IC, the isobutane gas is ionized with the ionization proportional to the kinetic energy.

The mass of the particle can be found through the classical kinetic energy equation:

$$E = \frac{1}{2}Mv^2$$

Rearranging to solve for mass, we get:

$$M = 2\frac{E}{v^2} = 2E\left[\frac{t}{l}\right]^2$$

Where *l* is the distance between the two carbon foils and t the time of flight (ToF).

To extract atomic number, we use the IC as a time projection chamber. A pulse is induced on the cathode when ionization occurs in the gas, and on the anode when the electrons pass the Frisch grid. These pulses functioning as an energy reading as well as a start and stop time. The time differential between the two pulses is directly proportional to R, the range of the particle, from which Z, the charge can be derived.

The fission spectrometer has been equipped with HPGe detectors which are placed next to the californium source holder. The first MCP signal is used as a fission gate and gammas emitted by fission products can be measured relative to that time. As with the TKE, we are looking at gamma rays correlated with ionization chamber events, though in this case, with the sharp fission timing from the first MCP, the ionization chamber data aids in correlating slightly delayed (>50ns and beyond) fission fragments and the gamma rays they emit.

As mass plot was generated and compared to Japanese Atomic Energy Agency (JAEA)

As mass plot was generated and compared to Japanese Atomic Energy Agency (JAEA) Fission Product data (Fig. 10) [3]. For a single amu resolution the FWHM/centroid mass for light fragments is 1/90 = 1.1% and for heavy fragments a more stringent 1/140 = 0.7%. The resolution for heavy fragments is broader than the resolution for the light fragments, so we get a wider heavy peak than JAEA data. Reducing energy straggling and thus broadening is important to improve this~~.~~ A thinner SiN ionization chamber window results in less energy loss, with the drawback that a thinner window means a greater risk of the window breaking, resulting in a break in the vacuum seal and isobutane flowing into the Time of Flight region.

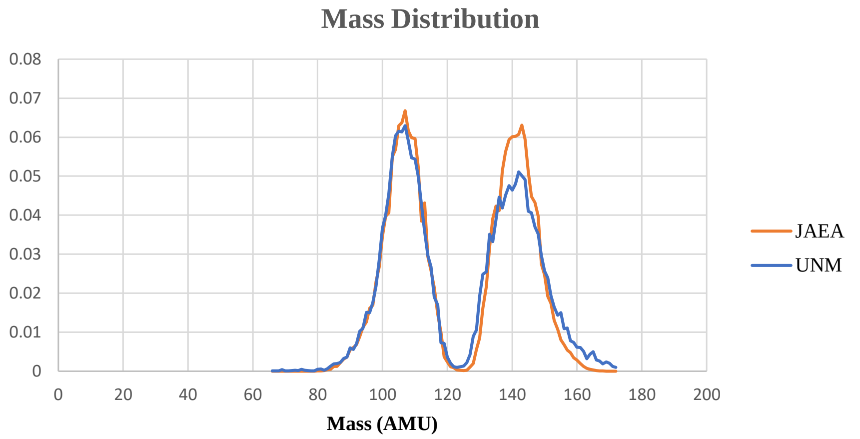

Figure 10 - UNM Cf-252 Mass Distribution compared to JAEA's Cf-252 Mass Distribution

The first MCP detector was used as a fission trigger, and down selecting to only those that give a time of flight within the time range for fission fragments, a histogram of the time difference between the MCP triggers and gamma signals is shown in Fig. 11. The peak is not as strong above background as we see with the much higher efficiency surface barrier test. These are gamma rays detected at the ionization chamber, approximately 80 cm from the Cf-252 source. The delay is primarily from processing electronics, as the fragments enter the IC about 50 ns after fission. The gamma ray spectrum gathered at the IC, Fig. 12, has a low intensity Cf-252 source. A second HPGe was added recently, and data collection is continuing.

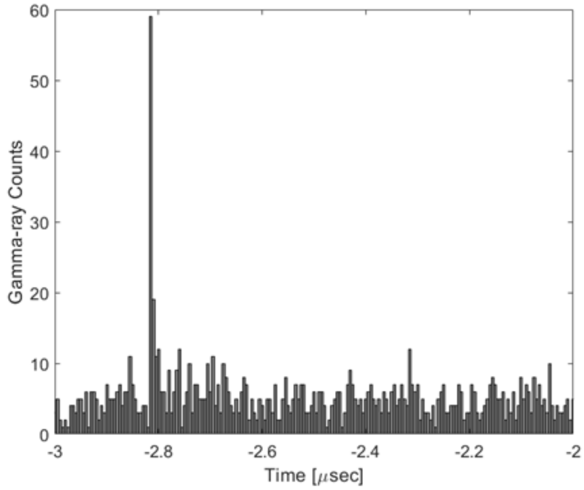

Figure 11 – Fission Gamma Burst

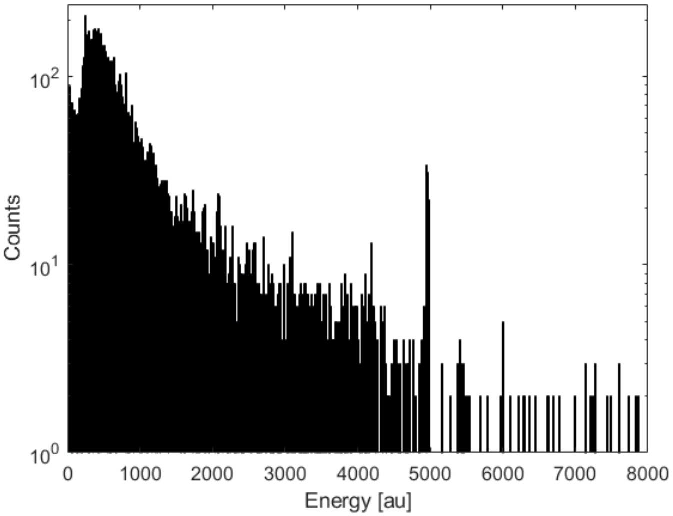

Figure 12 – Gamma Spectrum Overall

Future Work

We are able to efficiently fission tag gamma ray data using a U-235 target in a TKE, as well as tag Cf-252 spontaneous fission events with gammas at our lab at UNM using a surface barrier detector setup as well as with the UNM fission spectrometer. Moving forward, we will be taking the UNM fission spectrometer to LANL in November to perform fission product yield experiments using U-235 and Pu-239 fission targets. We will also continue our Cf-252 spontaneous fission research in the lab at UNM.

Citations

[1] Blakeley, R.; Development of The University of New Mexico Spectrometer for High-Resolution Fission Product Yield Data, Doctorate Thesis, Department of Nuclear Engineering, University of New Mexico, Albuqeurque, New Mexico USA, 2018.

[2] Duke, D.; Fission Fragment Mass Distributions and Total Kinetic Energy Release of 235-Uranium and 238-Uranium in Neutron-Induced Fission at Intermediate and Fast Neutron Energies, LA-UR-15-28829, Doctorate Thesis, Department of Physics, Colorado School of Mines, 1500 Illinois St., Golden, CO 80401,

[3] Nuclear Data Center, Japan Atomic Energy Agency, using JENDL FP Fission Yields Data File 2011. Accessed 2021 June 24, https://wwwndc.jaea.go.jp/cgi-bin/FPYfig