Developments in New Measurements of Fission Cross-Sections, Fragment Yields, and Prompt and Quasi-Prompt Gammas for Nuclear Data Needs

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Abstract. The University of New Mexico Fission Spectrometer was developed to measure fission product yield, as part of the LANL SPIDER collaboration. The spectrometer operates as an E-v detector to extract product mass event-by-event, with a time of flight region followed by an ionization chamber for kinetic energy measurements. By using the ionization chamber as a single-cathode/single-anode time projection chamber, stopping power and thus Z information is extracted, for coupled A and Z measurements. New work is being performed to add gamma ray detectors in the data stream, placed near the target region for prompt gammas and near the ionization chamber for quasiprompt (>50 ns) and later gammas, correlated with individual fission products. A stand-alone parallel plate ionization chamber (PPIC) is also being developed for fission tagging gamma ray data. The PPIC will also allow discrimination between charged particle out events and (n,n'γ), and discriminate between alpha emission and fission. Using layers in the PPIC, other targets can be measured simultaneously with a calibration target, giving relative fission cross sections. Past measurements with the spectrometer were performed at LANSCE and we plan to continue measurements there. The current work is supported by the NNSA Stewardship Science Academic Alliance.

1 Introduction

Nuclear data needs call for measurement of high-resolution fragment yields and energies for ^{239}Pu and ^{235}U fission. The Nuclear Energy Agency has begun to keep a list of high priority requests for data relating to nuclear energy applications [1]. This includes prompt gammas from ^{239}Pu and ^{235}U fission. Los Alamos National Laboratory (LANL) partners have also expressed the need for quasi-prompt gammas for studying fission daughter

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isomers, while quasi-prompt gammas from fission parent isomers are important to understanding pre-fission nuclear shapes for theory.

As part of the SPectrometer for Ionization DEtermination in fission Research (SPIDER) effort, we have built an E-v fission product spectrometer at the University of New Mexico (UNM) for particle-by-particle fission mass yield data. With the data from within approximately 50 ns of fission we are acquiring quasi-prompt (>50ns) independent mass yields. With the energy detector, an ionization chamber (IC), which is wired as a time projection chamber, range information and thus Z information can also be extracted. With both A and Z we have N information. Thus we have coincident E, v, A, Z, and N information for each particle. Under a new Stewardship Science Academic Alliance grant, gamma detectors, including HPGe, will be placed near the target region for prompt coincidence gamma data and near the ionization chamber for quasi-prompt to delayed gammas. To increase fission tagging geometric efficiency, a stand alone ionization chamber with the fission target within the gas will be used with the gamma detectors. When run at the LANSCE neutron facility at LANL, the neutron TOF can be used in coincidence with the fission to develop the data sets as a function of neutron energy. The full spectrometer and the stand alone ionization chamber can be run in tandem in the same neutron beam in optimize beamtime. The full spectrometer has been developed and is the focus of this proceeding. Future work will include the standalone ionization chamber and gamma measurements.

2 Experiment and simulation

The UNM Fission Spectrometer is an E-v spectrometer which measures the kinetic energy and velocity of particles which, following $E=\frac{1}{2}mv^2$, can be combined to extract mass. A schematic diagram and a cut through view of the spectrometer is shown in Fig. 1. Some fission fragments pass through the time of flight (TOF) region and into the energy detector. The TOF region consists of a start and a stop time detector. Each timing detector each has a thin carbon foil (~50 μg/cm^2 for the discussed experiments) the fragment passes through and ejects electrons. The electrons are reflected by an electrostatic mirror to a microchannel plate detector placed to the side to not interrupt the travel of the fission fragments. The TOF path length is 50 cm and is operated in the range of 10^{-7} to 10^{-8} torr.

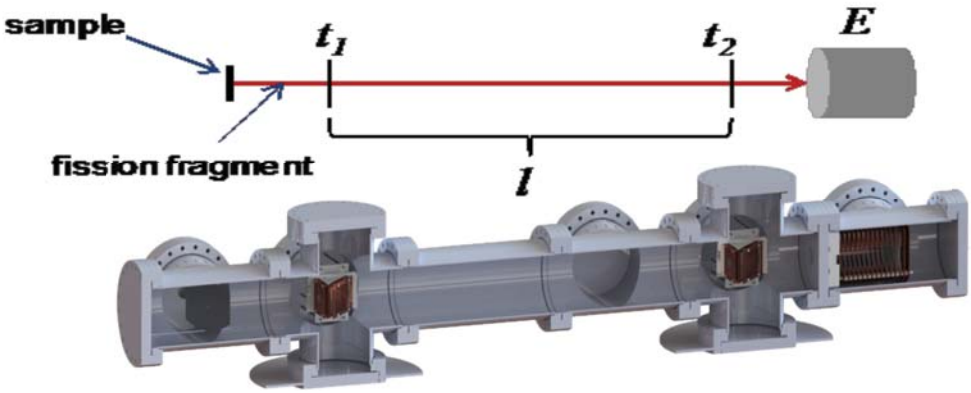

Fig. 1. (top) Schematic of time-of-flight region with target/sample region, t1 and t2 detectors and energy detection region. (bottom) Cut-through view of UNM Fission Spectrometer with target/sample region, t1, t2, and E detectors lined up with schematic.

Further along the path is the energy detector, a gas filled ionization chamber (IC) separated from the TOF region by a 200 nm (58 μg/cm^2) SiN window, Fig. 2. For the data discussed, the IC was operated with 70 torr of isobutane. IC detectors have better energy resolution for fission fragments than solid state detectors and suffer less cumulative damage. Gas cracking may occur with continued ionization and so new gas is cycled through the IC, with a refresh rate of 1 hour. The ionization chamber consists of an active region of about 8 cm between the cathode and Frisch grid, followed by an anode from which the energy pulse is read out. The entrance window consists of several 1 cm^2 SiN windows mounted in a stainless steel frame. This is mounted flush with the cathode annulus and is electrically connected with the cathode annulus to complete the cathode electrode. The cathode electrode is mounted on Teflon rather than directly to the vacuum flange to allow signal readout for range determination to extract Z. There is a series of guard rings between the cathode and the grounded Frisch grid to ramp down the voltage to produce a uniform electric field in the active region, which makes the energy pulse more uniform and allows the IC to be used as a time projection chamber for range determination.

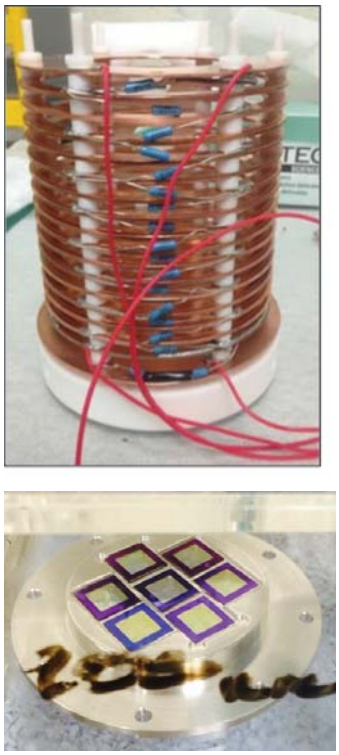

Fig. 2. (left top) Ionization chamber electrodes with cathode on top, the Teflon on the bottom is just structural, (right top) cut through of IC in use with fragment coming from the left, and (bottom) window frame with 7 SiN windows.

The energy of each particle in the IC is slightly lower than the energy of that particle in the TOF region due to the second TOF foil and the SiN window between the regions. The energy loss must be added back to correlate these two regions. We are pursuing beam calibrations, but for now this addback is performed using simulations. Comparison of SRIM-2013 [2,3] and MCNP6.2 [4] and our ^{252}Cf source measurements, Fig. 3, shows that MCNP overstates energy loss while SRIM understates the loss, making accurate addback using simulations difficult.

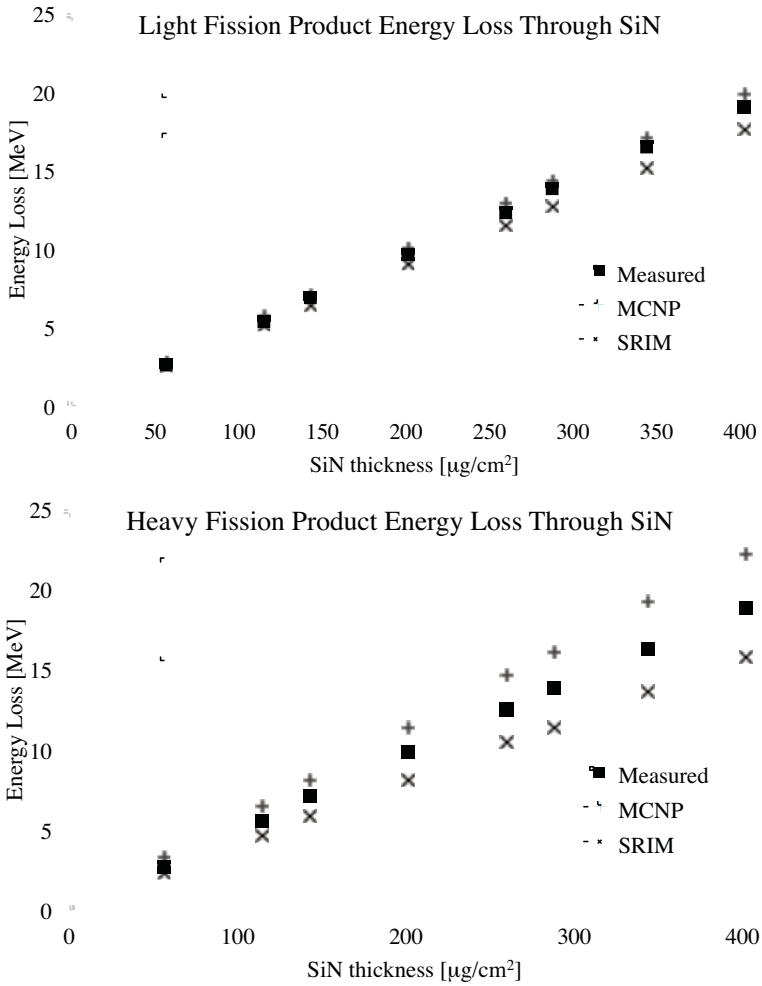

Fig. 3. Measured energy loss for ^{252}Cf light and heavy fission products through various thicknesses of SiN windows, measured with a Si surface barrier detector, compared with MCNP and SRIM predicted values. More details of this part of the work can be found in Baldez *et al*. [5].

For range determination, we follow the active cathode method of Sanami *et al*. [6] The fragment enters the IC and ionizes the isobutane gas. The electron cloud created begins drifting towards the Frisch grid, inducing a pulse on the cathode, and when it finally passes the Frisch grid it induces a pulse on the anode. The time difference between the beginning of the cathode and anode signals then relates to the range of the fragment in the IC gas. The Bethe formula relates stopping power to particle Z, but in this case the particle is not fully ionized. There is at least some proportionality expected and light and heavy fragments do show different ranges. To understand the relation between A, E, Z and range, SRIM simulations were performed and used to extract Z from the measured and extracted E, A, and range of each particle. SRIM predictions of range were close to the measured values for light fragments, about 1% high, though predictions were about 5% low for the heavy fragments.

3 Results

A plot of raw correlated TOF-IC values is presented in Fig. 4 (top). The heavy and light fragment concentrations are discernible at the lower and higher IC channels, respectively. The high amount of scatter may be due to the support wires for the carbon foils, the electrostatic mirror wires, and the many window frame edges. Using MCNP to determine the energy corrections, the masses were extracted, and are presented in Fig. 4 (bottom). Corrections with SRIM gave lower masses for the peaks. It is not clear why MCNP energy addbacks should work so well, since MCNP overestimates energy losses. Beam calibrations of energy loss are needed.

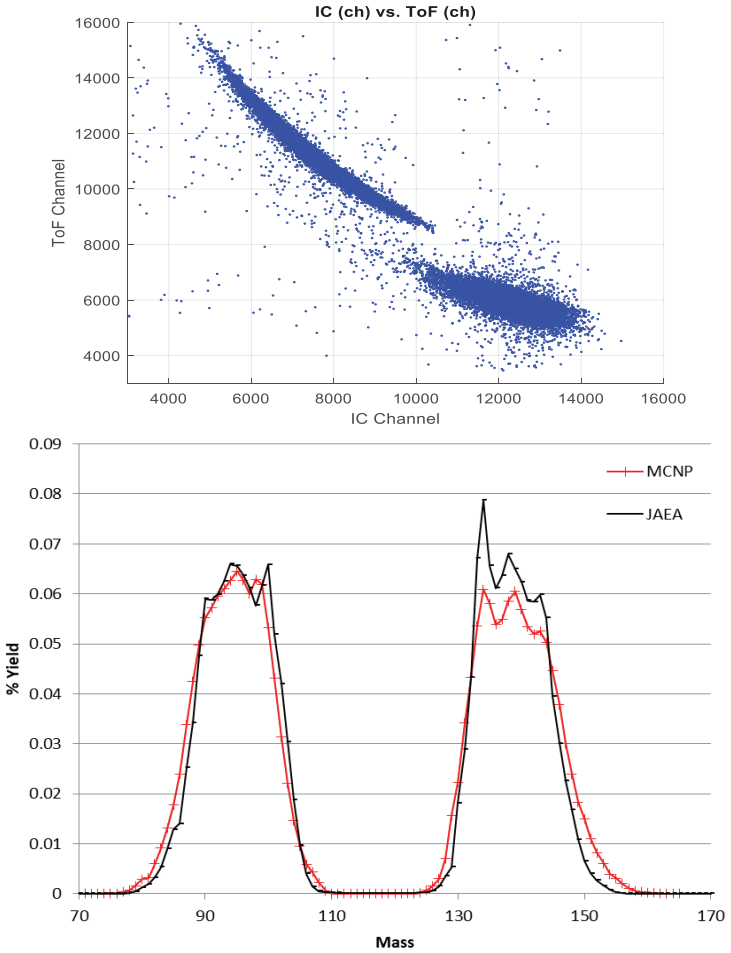

Fig. 4. (top) An example of TOF vs IC raw fission product data for ^{235}U and (bottom) extracted masses from this data using MCNP simulation based energy corrections compared with table values from JAEA.

Z information, extracted from the simulated range vs. A, Z, and E relations, was combined with A information to extract N for each particle, which is presented as Z vs. N and overlaid on stable nuclide positions in Fig. 5. The light fragment Z values are reasonable, though the heavy fragment Z values are too broadly spread, perhaps due to heavy fragment range simulations being too far from measurements. Calibration of range

response and reconstruction of Z will be performed using x-rays from the ^{252}Cf source for identification.

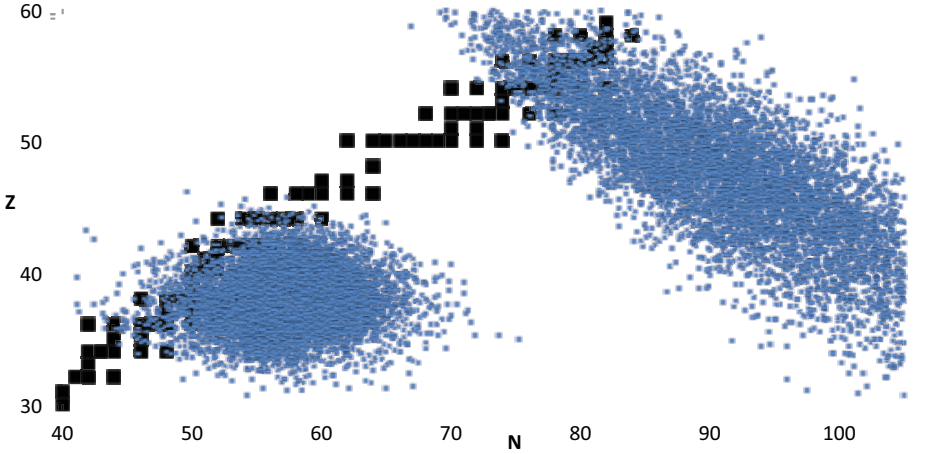

Fig. 5. Presentation of (N,Z) values extracted for each measured particle, overlaid on the positions of stable nuclides in black.

4 Further work

Further work is required. Beam calibrations were mentioned, to understand the pulse height response of the ionization chamber to different species at different energies, and to understand energy losses through the system. The range of particles in the IC must be better understood, which can also be studied with beam calibration. In addition, we will perform measurements of gamma rays in coincidence with the measured fission fragments, with both prompt gammas near the fission source/target and delayed gammas near the ionization chamber, with delayed being from 100 ns and on. To increase measurement efficiency, a stand alone ionization chamber, following Tovesson *et al*. [7], will be used for fission tagging gamma coincidences.

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