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Title: FY2017 Report on NISC Measurements and Detector Simulations

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# FY2017 REPORT ON NISC MEASUREMENTS AND DETECTOR SIMULATIONS

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## OVERVIEW

FY17 work focused on automation, both of the measurement analysis and comparison of simulations. The experimental apparatus was relocated and weeks of continuous measurements of the spontaneous fission source $^{252}$Cf was performed. Programs were developed to automate the conversion of measurements into ROOT data framework files with a simple terminal input. The complete analysis of the measurement (which includes energy calibration and the identification of correlated counts) can now be completed with a documented process which involves one simple execution line as well. Finally, the hurdles of slow MCNP simulations resulting in low simulation statistics have been overcome with the generation of multi-run suites which make use of the high-performance computing resources at LANL. Preliminary comparisons of measurements and simulations have been performed and will be the focus of FY18 work.

## MEASUREMENTS

The measurement apparatus was relocated to technical area 35 in the early summer. This relocation allowed un-cleared persons working on the project the ability to access and view the experimental set up. Four EJ-301 detectors were arranged 100 cm from $^{252}$Cf spontaneous fission and photon calibration sources, Figure 1. Mid-way through the summer detectors were swapped with bubble-free EJ-301 detectors. Some photon (Cs-137, Co-60) sources were measured so that they could be incorporated into the analysis of these measurement results.

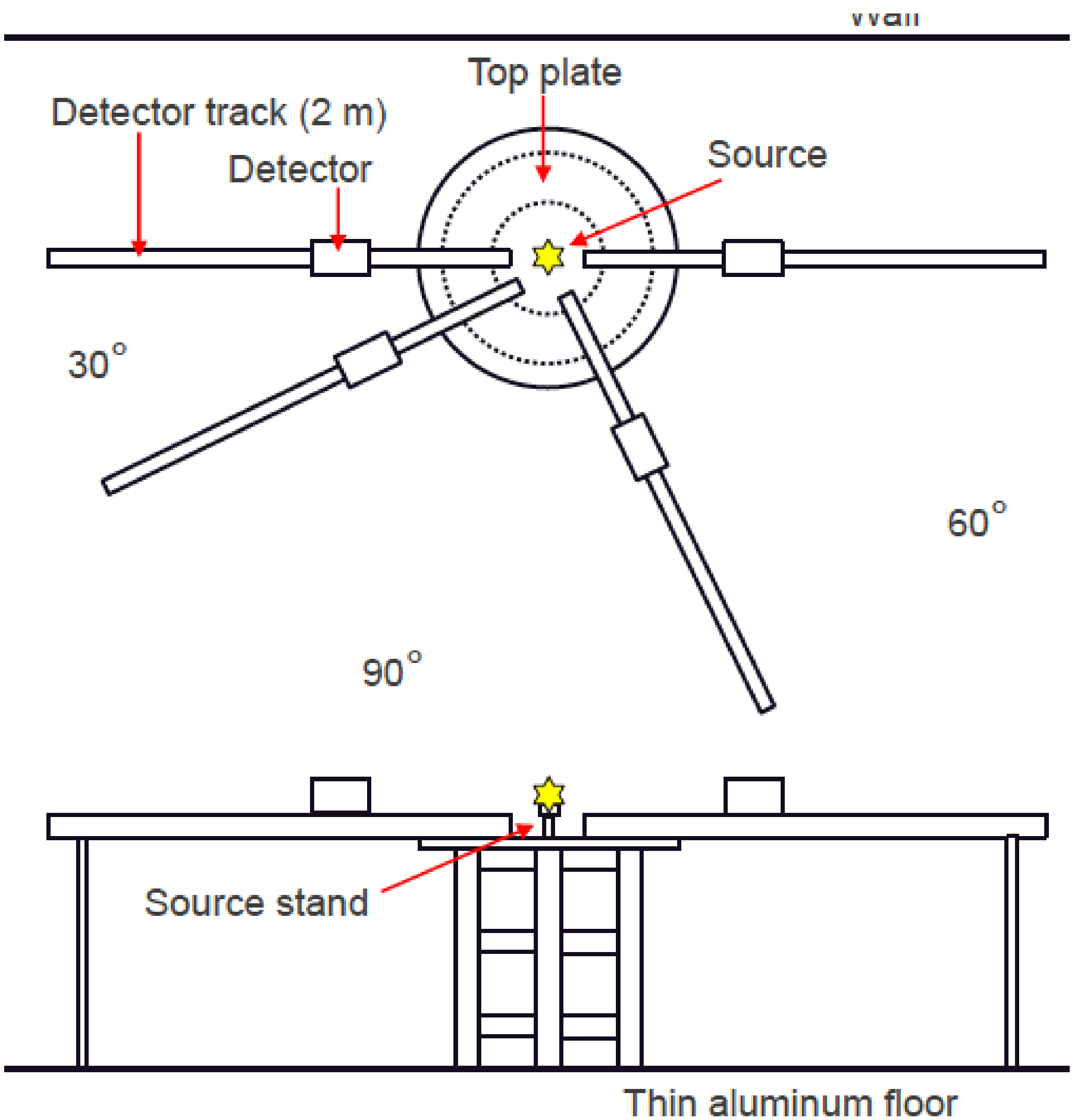


Figure 1: TA-35 Arrangement of Cf-252 source and EJ-301 detectors

## Post-Processing Measurement Results

Binary files containing digitizer waveforms are converted to ROOT data analysis framework format using a previously provided conversion script. This process at the beginning of FY2017 was quite tedious as every file contained just one hour of data and had to be converted one at a time. This process is now streamlined via a bash script which allows an automated conversion of all measurement binary files with a simple terminal command.

Files are now in ROOT trees with branches containing:

- Digitizer waveforms for each pulse sampled at 50 MHz for 1.024 $\mu s$.
- A 32 bit word time stamp associated with each event
- The detector number for each event

## Analyzing Measurement Results

In FY17 an automated analysis program to be applied to measurement data was written, tested and continues to be used. This analysis is performed on LANL's moonlight high performance computer using ROOT. The entire analysis from energy calibration to generation of correlated fission plots is automated. The purpose of this automation was to apply a consistent analysis across all detector arrangements and auto-generate plots which identify experiment and/or analysis anomalies. Details and examples of the output are described in the report "Automated Analysis of Correlate Fission Measurements at TA-35" which was distributed to collaborators on this project in July 2017. A short summary follows.

Execution of this analysis is simple, go to the directory containing measurement output (in ROOT files) and execute the terminal command **sbatch analyze_slurm**. This creates a job in the HPC queue which will perform the entire analysis with no further input required by the user. The analysis steps are executed as follows, more details are in the associated report:

- Determines how many $^{137}$Cs calibration files are in the directory, merges them.
- Determines how many background files are in the directory, merges them
- *Calibration_energies.C* performs a check on calibration and background files
- *Calibration_energies.C* converts digitizer waveforms of calibration and background files into energies and pulse shape discrimination values for each detector.
- *Calibration_energies.C* generates *detector_params.txt* which contains constants for slight energy calibration differences between detectors, to be used when analyzing $^{252}$Cf results.
- Then for each $^{252}$Cf file the following process is applied:
- *Energy_bash.C* reads digitizer waveforms and generates PSD (pulse shame discrimination) and energy values for each event using *detector_params.txt*
- *Energy_bash.C* identifies particle type (neutron or gamma) and whether a count is saturated.
- *Energy_bash.C* generates an output ROOT file containing only neutron counts exceeding 200 keVee
- *Sorter_bash.C* sorts the neutron events in time
- *Corr_bash.C* compares the timestamps of all neutron events, designating a closest event in time for each neutron count. These neutron pairs are saved together along with their energies, relative time differences, and PSD values.
- *Plot_results.C* generates a series of figures for all neutron events recorded in the measurement analysis. Events separated by less than 100 ns in time are currently designated as of interest and plotted in several ways.
- All plots are saved in and a new LaTeX report detailing analysis results is easily generated with the command *pdflatex report.tex*. The generated report contains plots of all measurements so that they can be compared.

Some examples of plots generated in this analysis are below.

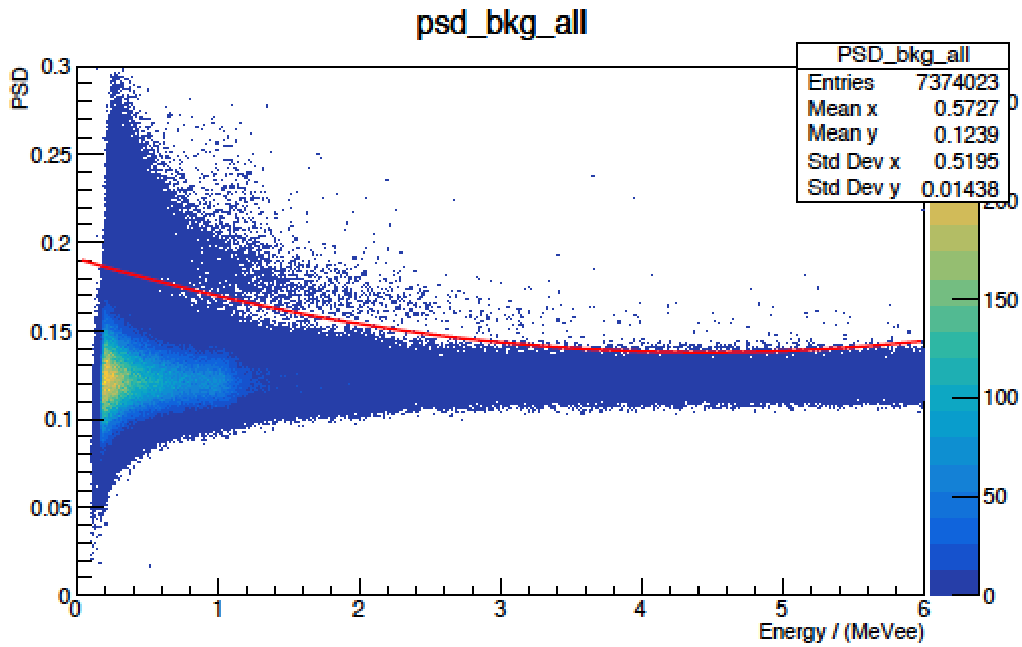


Figure 2: Example measurement PSD plot as generated by automated analysis.

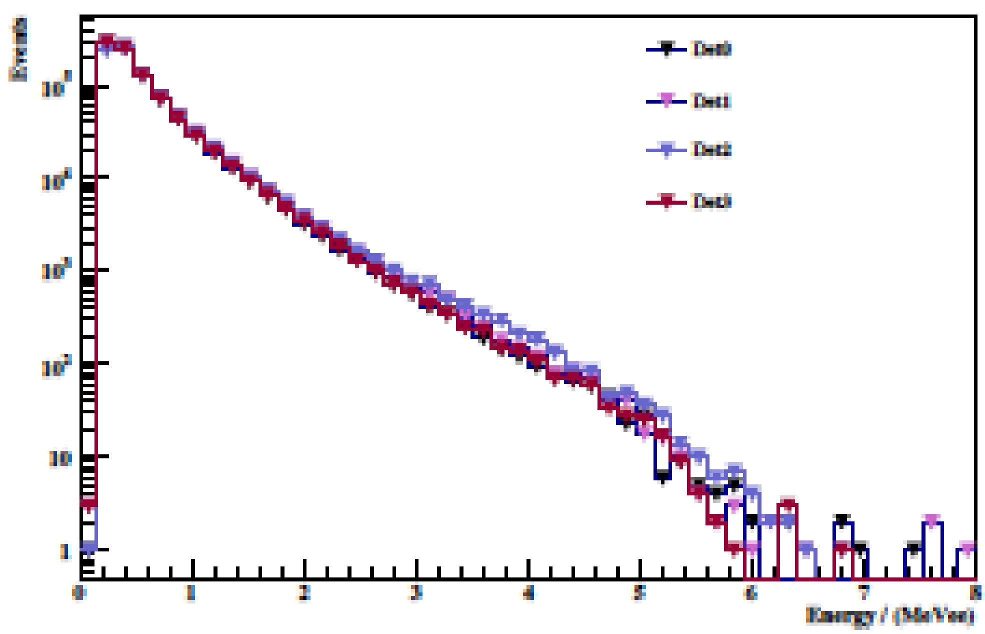

Figure 3: Measured neutron spectra of all four detectors

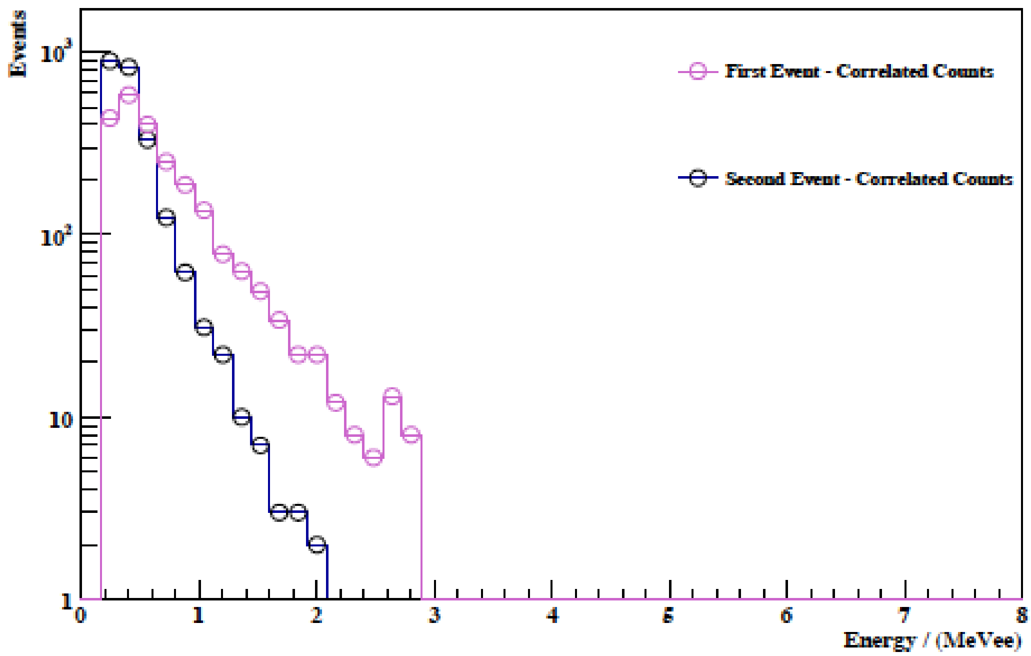


Figure 4: Measured differences in energy distribution of correlated events separated by detector arrival time. Differences in energy spectra are believed to arise because the lower energy neutrons take more time to travel to the detector.

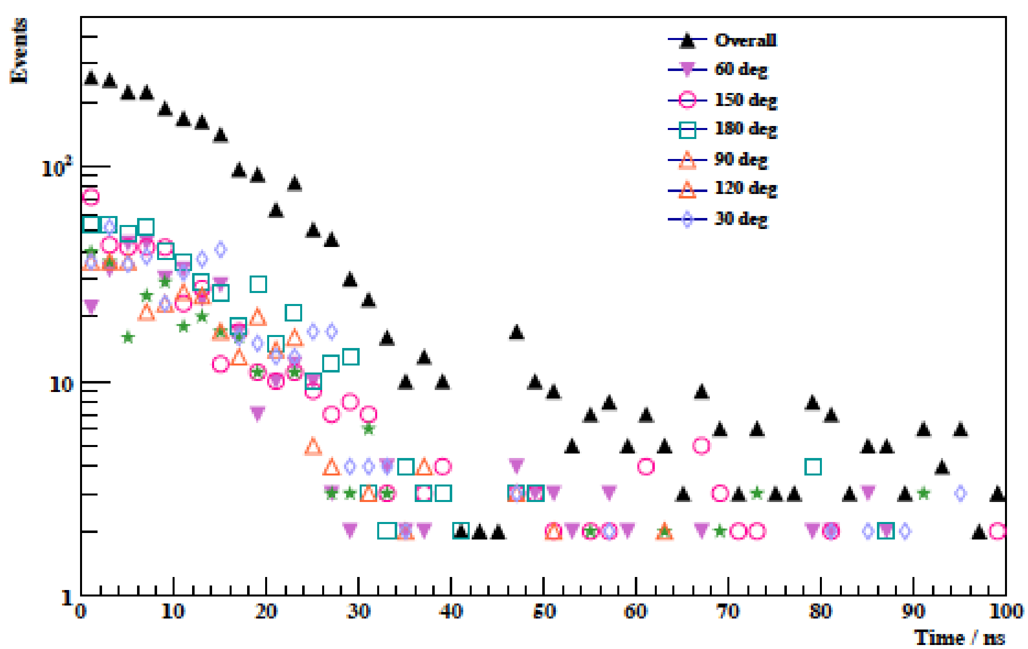


Figure 5: Time distribution of first and second correlated (or cross-talk) events in measurement.

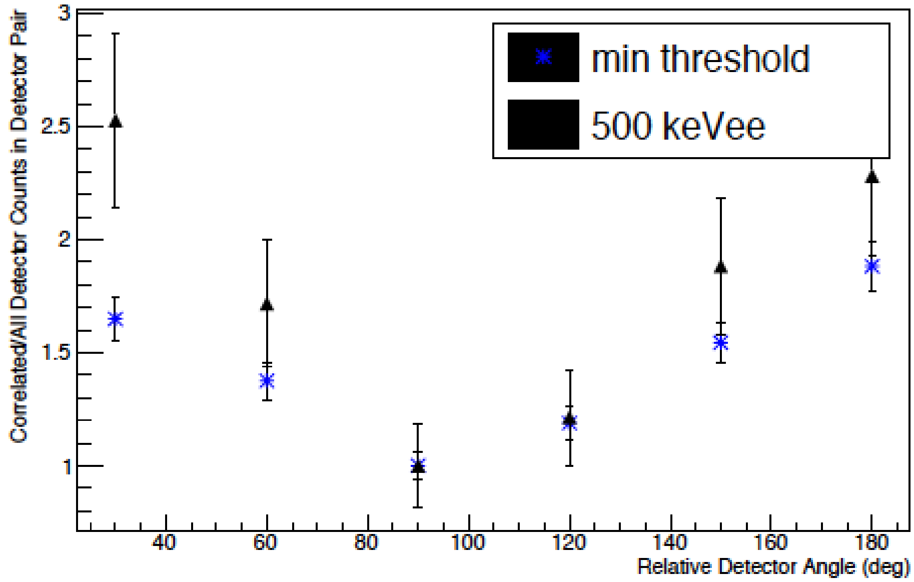


Figure 6: Measured angular correlations as a function of energy threshold. Values are normalized to unity at 90 degrees.

## MCNP6.2 SIMULATIONS

### Stand Optimization

An additional component of the project included characterizing the effect of stand design on scatter contributions to the measured results in MCNP6.2. MCNP simulations of three different stand designs shown in Figure 7 were executed and the amount of scatter quantified. It was determined that the currently deployed stand design generates a 10 % increase in scattered neutrons (when compared to the unrealistic design of detectors suspended in air). This contribution could be reduced five-fold via the removal of a large portion of the stand material, as shown in Figure 7. It should be noted that all simulations performed had the detectors 50 cm from the source rather than the currently deployed 100 cm so the actual contribution of scatter and cross talk should be less than simulated.

A second expected source of scattering contributions is from closely adjacent detectors. FY18 plans for data collection include taking smaller relative detector angles which will make an investigation of this scattering contribution important.

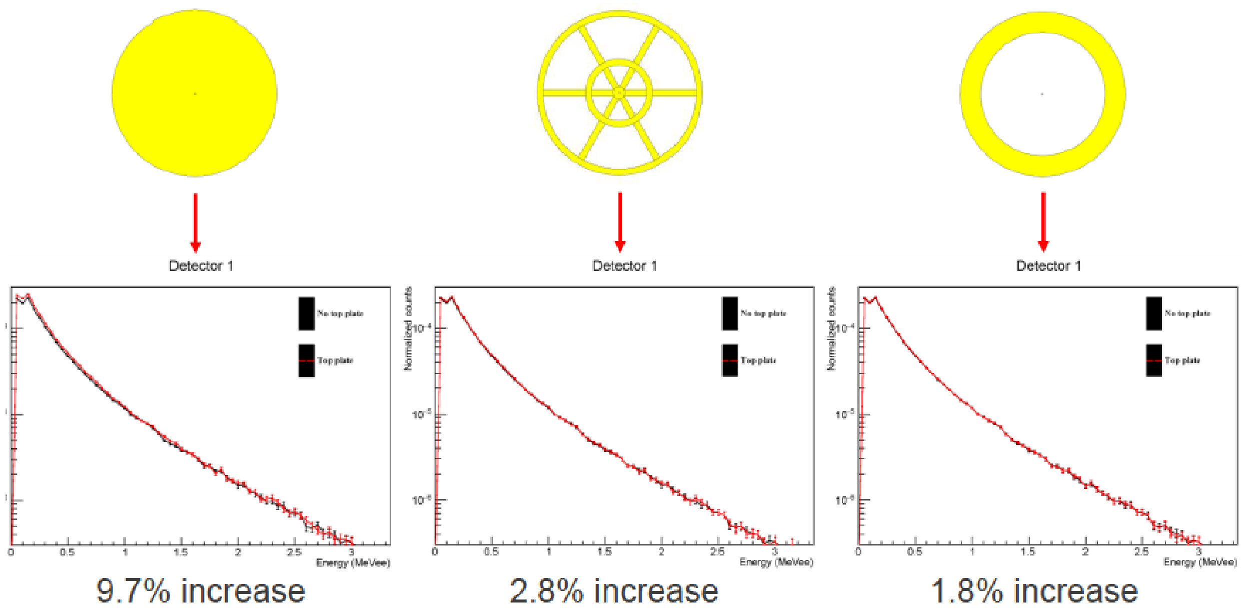


Figure 7: Stand optimization studies demonstrate a 5 fold decrease in scatter can be achieved with a new tabletop design.

## Fission Models in MCNP6.2 Simulations

MCNP6.2 simulations are performed for 11 different detector angular positions (30 – 180 degrees apart in 15 degree intervals) and for four source definitions. Those definitions are as follows:

Table 1: A description of all source definitions used in MCNP6.2 simulations of the TA-35 arrangement.

| NAME | DESCRIPTION |
|---|---|
| **Watt** | MCNP spontaneous fission option which generates spontaneous fission neutrons with no angular dependence (isotropic) |
| **Test** | These source neutrons are emitted on at a time with a Watt fission neutron spectrum. Any observed doubles in these simulations should be solely due to cross-talk between adjacent detectors. |
| **CGMF** | These MCNP simulations use pre-compiled correlated fission events generated by the CGMF event generator. A special MCNP executable was created for these simulations as the default CGMF option was too slow for reasonable detector statistics. |
| **FREYA∫** | Spontaneous fission neutrons are generated with FREYA’s event data generator. |

Initially MCNP simulations were generated with scintillator detector volumes placed 50 cm from the source. These particular simulations could not be run in parallel so each run would be set for an 8 hour execution time and repeated several times with an updated random number seed. After analysis it was determined that these runs were producing inadequate counting statistics so the focus shifted to streamlined MCNP execution. A job scheduling program was generated which fully utilizes all 16 processors / node when executing across 30 nodes at once. This allowed the generation of sufficient statistics for comparisons with measurements.

## DETECTOR RESPONSE WITH DRIFT

The detector response function toolkit (DRiFT) has been used to post-process MCNP simulations and generate appropriate detector response. DRiFT features have been added specifically for this project and include: tracking source particle energy for all events (and non-events), expanded output formats, and digitizer waveform generation. These features were detailed in "Characterizing Scintillator Detector Response for Correlated Fission Experiments with MCNP and Associated Packages" which is in review with *Radiation Physics and Chemistry*. DRiFT applies detector response to MCNP output and outputs the data in a format identical to post-processed measurements (i.e. ROOT trees). It also outputs additional energy including: i) the energy of the source particle(s) which initiated the correlated counts, and ii) a flag indicating if the count was a true correlated (from two different neutrons) or cross talk (when one neutron enters both detectors).

## Simulation Output for Correlated Fission Event Generators CGMF and FREYA

Angular correlations for increasing energy thresholds are shown for FREYA and CGMF in Figure 8 and Figure 9 respectively. There were distinct differences between the two as CGMF exhibited stronger angular trends. FREYA predicted an interesting dip at 105 degrees for increasing energy thresholds which should be compared to measurements later in this project.

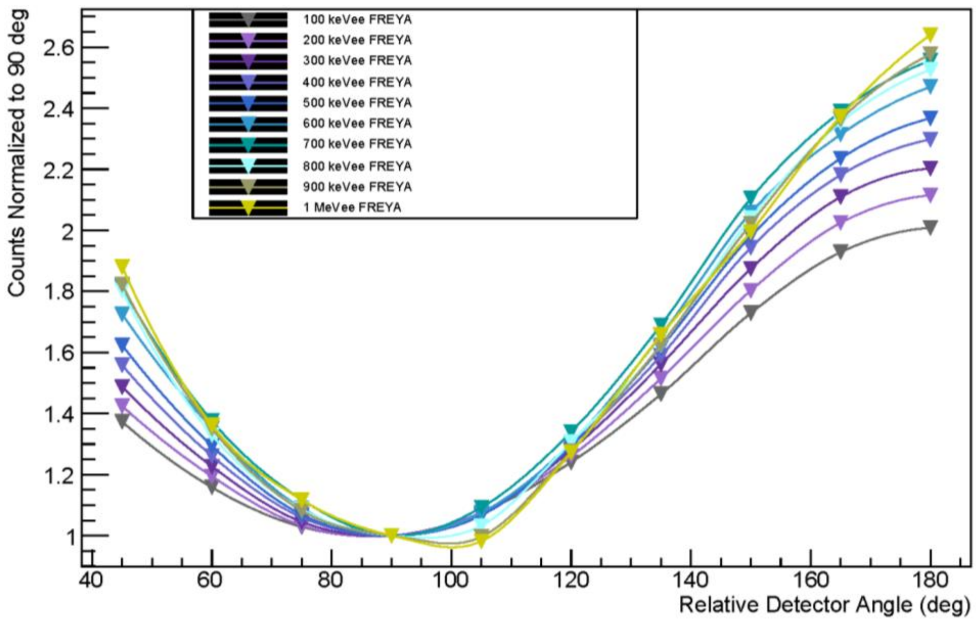

Figure 8: Simulated FREYA angular distributions with increasing energy thresholds.

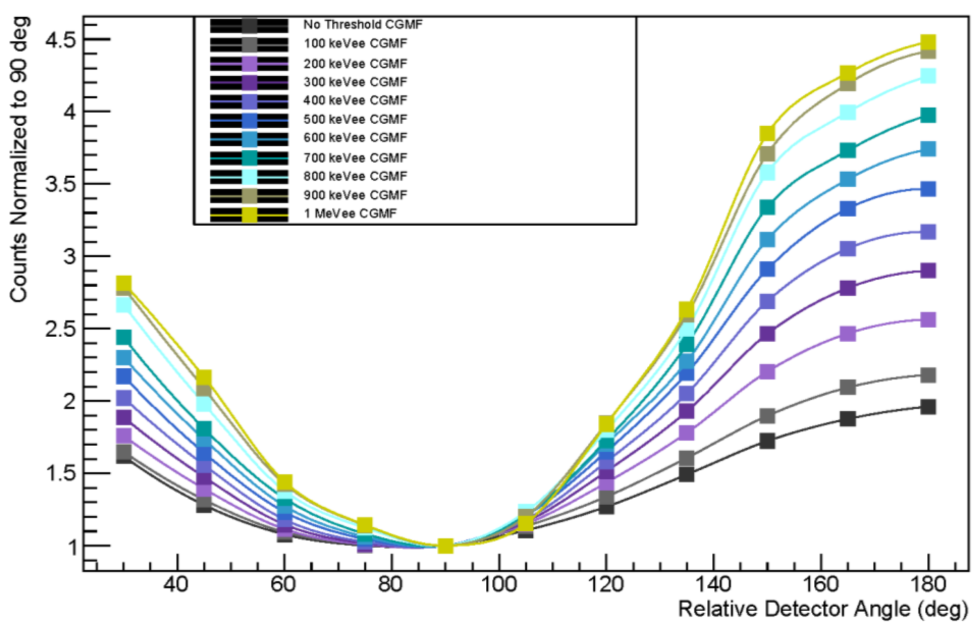

Figure 9: CGMF simulations of angular distributions with increasing energy thresholds.

## COMPARISON OF MEASUREMENTS AND SIMULATIONS

Initial comparisons of correlated fission measurements and simulations were performed in the summer of 2017. These comparison were not complete as simulations had detector to source distances of 50 cm, half the distance of actual measurements. This was done as originally reasonable statistics were barely achievable at 50 cm let alone 100 cm. The new processing scripts have facilitated very recent simulations with the correct source to detector distance of 100 cm. The geometry in these simulations is relatively simple, it is just two detector volumes suspended in air. The next step in simulations is incorporation of the detector stand in simulations and observing the effects of scatter.

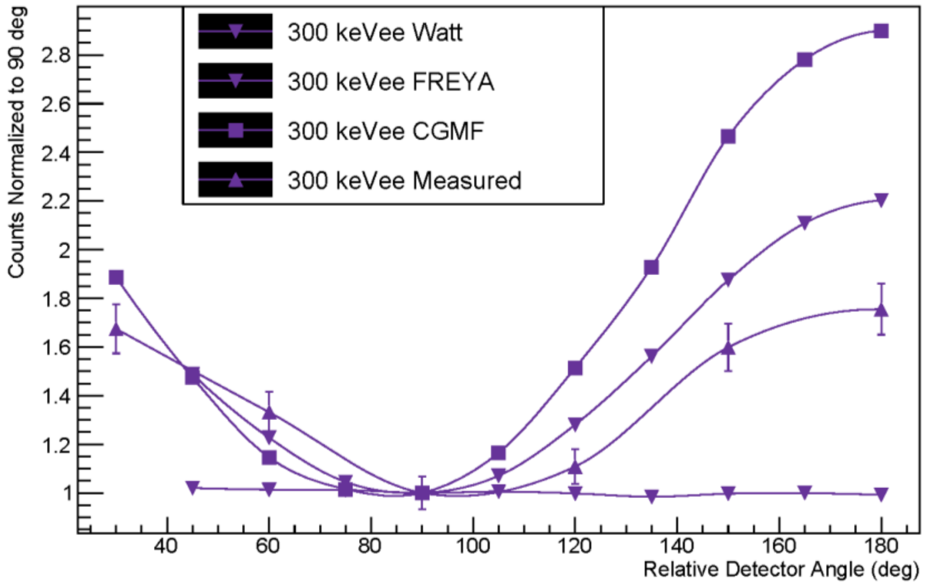


Figure 10: A rudimentary comparison of simulated and measured angular distributions. Results were not expected to agree as incorrect source to detector distances were used in simulations.

**FUTURE WORK**

FY18 plans include the continued collection of data using the "NISC[1]" arrangement for $^{252}$Cf with emphasis on consistent data collection with minimal disturbance to the detector arrangement. When sufficient counting statistics are obtained comparisons will include those with higher energy thresholds (exceeding ~1 MeVee) between measurement and all event generators.

Simulation future work will focus on higher fidelity simulations which will include the detector coverings, stand, floor, and adjacent wall. The Lestone fission model output will also be included in simulations and compared to measurements. Currently the only comparisons between measurements and the correlated fission event generators have been visual, a more rigorous comparison will be performed in FY18.

**DOCUMENTS AND PRESENTATIONS PRODUCED FY2017**

[1] The "NISC" arrangement is no longer located in the NISC building, rather it has been re-located to Technical Area 35 in building 27.

M.T Andrews, M.E. Rising, K. Meierbachtol, *et. al*. “Characterizing Scintillator Detector Response for Correlated Fission Simulations with MCNP6.2 and Associated Packages” *Submitted to* Journal of Radiation Physics and Chemistry (2017).

T. Jordan, M. Andrews, K. Meierbachtol “Anisotropic fission neutron emission: Validating fission models with characterized measurements” XCP-3 Student Seminar, Los Alamos National Laboratory, (2017) LA-UR-17-27386.

M.T. Andrews, “Automated Analysis of Correlated Fission Measurements at TA-35” Internal Report for NA-22 work.

M.T. Andrews, “Recording Source Particle Information in DRiFT” Los Alamos National Laboratory Technical Report, LA-UR-17-24062 (2017).