# NE 204: Advanced Concepts in Radiation Detection and Measurement
## Experiment 9: Neutron Detection and Imaging Using a Scatter Camera

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## Purpose

In this experiment, an array of EJ309 liquid scintillation detectors will be used as a neutron scatter camera to detect a neutron source, as well as determine the position of the source and the neutron energy spectrum.

## Approach

This experiment extends the experimental procedure of experiment 4 (neutron detection and PSD with liquid scintillators) to include neutron imaging. The imaging modality is based on the kinematics of neutron scattering, relying on the detection of multiple time-coincident interactions from neutrons scattering in an array of liquid scintillation detectors. Unlike gamma-ray imaging, where it very difficult to recover information about the time-of-flight of photons except with the fastest of gamma-ray detectors, sufficient kinematic information can be collected based on the travel time between two neutron detectors (placed sufficiently far away) to recover the energy and direction (up to a conical ambiguity) of the incident neutron. 24 EJ309 scintillators are arranged in two planar arrays of 3x4 detectors with variable spacing. The distance between the planar arrays can be adjusted to control the tradeoff between TOF precision and the efficiency of collecting multiple-neutron-scatter events. Each detector is sealed and is instrumented with a PMT, whose signal is subsequently digitized using SIS digitization modules (either SIS3320 or SIS3316) with sampling rates $> 100$MHz.

Perform each of the procedures detailed below on a subset of at least 2 detectors (one from each scatter plane). If time permits, consider expanding your analysis to more detectors to enable 2D neutron imaging.

### Proton Recoil Energy

#### Required

- Perform an energy calibration for each cell using the Compton edge from a $^{137}Cs$ gamma-ray source (cf. experiment 4). This procedure determines the conversion from the integrated voltage signal $E_{obs}$ to the *electrion-equivalent* energy, $E_{ee}$.

- Using one of the quenching factor formulae from the literature (see below), determine the threshold in $E_{ee}$ and $E_{obs}$ needed in order to be sensitive to 500 keV *proton* recoils.

## Time-of-Flight (TOF)

### Required

- Develop and implement an approach for determining the neutron time-of-flight between two scintillators. Implement a fast filter to recover the "arrival time" of the interacting particle in the scintillator.

- Plot the distribution of TOF for a set of coincident events measured between a pair of detectors (1 in each plane). Identify features in this distribution corresponding to gamma-ray events vs. neutron events.

- Perform a TOF calibration using a $^{137}Cs$ gamma-ray source. Note that variations in PMT characteristics, cable lengths, etc. can cause offsets that vary between different pairs of cells. Identify the time offset corresponding to "instantaneous" coincidences between each pair.

- Calculate a reasonable time coincidence window that will allow sensitivity to neutrons with an incident energy of 1 MeV that deposit 500 keV in the first interaction.

## Neutron Spectroscopy

### Required

- Use the PuBe neutron source to acquire data and select coincident events based on the above analysis.

- Plot the distribution of incident neutron energies.

### Optional

- Acquire data with a different neutron source, e.g. $^{252}Cf$, and compare the two neutron spectra.

- Quantify the differences between the spectra.

## Scatter Angle Determination

### Required

- For the same set of coincident events collected in the previous procedure, calculate and plot the scattering angle $\theta$ for each coincident event.

- Identify the features of this distribution of scattering angles.

- What are the limits of available angles due to the thesholds, coincidence window, and mathematics?

- What are the limits of available detector angles as a result of the system geometry?

- Identify possible sources of "incorrect" events.

### Imaging

#### Required

- For a single pair of detectors, make a 1D "image" by summing a unit Gaussian distribution centered at $\theta$ for each event.

#### Optional

- Calculate the uncertainty in the scattering angle, $\delta\theta$ for each coincident event. How does this uncertainty affect the imaging?
- Attempt to image a point source at multiple different angular locations.

## Additional Information

### Proton quenching factors

$$E_p^{UM} = 0.035E_{ee}^2 + 0.1424E_{ee} - 0.0362 \tag{1}$$

$$E_p^{Bachelor} = 0.028E_{ee}^2 + 0.215E_{ee} \tag{2}$$