Remote Lab - Poisson Statistics Part 2

In this lab module, you will create a toy model of the Poisson Statistics experiment, simulate the results of the experiment, and compare it with real data.

In addition to answering all the questions, take notes throughout this activity. Your notes should be a record of the analysis, calculations, and other activities you did in class, including software used, websites visited, readings that you looked at, etc. The purpose is to help us follow along with the work that you did in class, and to make it possible for someone to be able to re-create this later.

Checkpoints where you should discuss your work with an instructor are in bold.

There is a wide variety of possible assumptions and methods to use for these exercises, and there is also a wide range of possible complexity to include in this simulation. As long as you describe these assumptions and methods and their motivation, and work on this throughout the lab session, you should receive full credit.

Section 1 – Sketching a Toy Model

Q1. First, make a sketch of the experimental setup, as you remember it and as described in the write-up and your lab notebook. This sketch and its details will be used to create our model. This does not need to be 100% accurate, and the instructors can help you with important details.

Some suggested details to include:

a. Estimated size, shape, mass, and age of the radioactive source, Cs-137
b. Estimated size and orientation of the NaI scintillator crystal
c. Layout and mass of lead shielding bricks
d. Overall layout of setup (placement on table, what's nearby)

Hint: this webpage describes a very similar experiment and has some extra details and diagrams:

https://www.mirion.com/learning-center/lab-experiments/gamma-ray-detection-with-scintillators-lab-experiment

Hint: this is very similar to the source we use:

https://unitednuclear.com/index.php?main_page=product_info&cPath=2_5&products_id=819

Checkpoint 1: Share your sketch with the instructors on Teams, and finalize any geometric details and dimensions of the model.

Section 2: Adding more details to the model

Q2. No simulation is completely accurate, and you probably don't have the time or information to simulate a realistic experiment.

a) List some of the aspects of the experimental setup that you think are important to include in the simulated model, regardless of your own ability to accurately model them.

b) Modeling geometry: Based on your sketch from Section 1, or adding details to your sketch from Section 1, what are the details of the source and detector geometry that are important to simulate the measurements made in lab?

c) Detector properties: What are some relevant detector properties that affect the measurement? List at least one, and what needs to be known to include it in your simulation.

d) Modeling backgrounds: We can estimate the background rate of gamma rays coming from all other radioactive decay sources near the experimental setup. What are potential sources of background radiation? Add these to your sketch from Section 1, with some details of relevant geometry.

e) In the lab experiment, you varied the distance from the source to the detector. Describe how this data could be used to verify your model.

Section 2 – Initial Simulation of Radioactive Decay

Q2. Simulating radioactive decay. Next, we'll simulate the decay of the radioactive source, in the programming language of your choice (preferred format: Jupyter notebook through Google Colab: https://colab.research.google.com/, but any method is ok).

a) Write a simple code that generates a Monte Carlo simulation of the radioactive decay of a collection of atoms. You'll need to define the following parameters, using the estimated properties of the Cs-137 source:

   Number of atoms, N
   Lifetime, tau
   Simulation time interval, dt
   Duration of the experiment, T

   To simulate the decay, you will also need some way to generate a random number.

   The output needs to include values for the number of decays, and values used for dt.

During each time interval, dt, the code needs to check on each remaining cesium atom once. To determine if that atom decays, generate a random number between 0 and 1 for that atom. The probability that the atom decays during that time interval is dt/tau. If the random number is less than dt/tau, the atom decays. If the random number is greater than dt/tau, the atom does not decay. Keep track of which atoms have decayed, or at least how many atoms have decayed, and remember to adjust to not check on atoms that have already decayed.

Generate the plot for a range of time periods, **choosing an appropriate dt for each one**. Pay attention to how long the code is taking to execute, and describe any modifications to assumptions to speed up the calculation.

i. Starting from when the source was made to this year
ii. A 1 week period around the time the experiment was performed
iii. A 1-hour period of time
iv. A 5-minute period of time

b) Compare the output of your simulation code to the analytical prediction for each time period: **N*dt/tau exp(-t/tau)**

Do any of the time periods have an especially good or bad fit to the analytic model?

Checkpoint 2: Share your code and the output plots with the instructors on Teams.

c) With the same simulation output, now generate histograms of the number of decays for each time interval dt, for each time scenario. The bins of the histogram will be the number of time intervals that had 0 decays, the number that had 1 decay, etc.

d) Evaluate how this compares with the theoretical expression, the Poisson Distribution:

$N(k) = (T/dt)(N*dt/tau)^{K}\ \exp(-N*dt/tau)/k!$

Checkpoint 3: Check in with the instructors on whether the statistical behavior compared to what was found in the original experiment data.