SOCIETY OF PHYSICS STUDENTS
An organization of the American Institute of Physics

SPS Chapter Research Award Proposal

Project Proposal Title	Neutron Energy Distribution of an AmBe Source at the MGH Proton Center
Name of School	Suffolk University
SPS Chapter Number	6917
Total Amount Requested	1,986.42

Abstract

At Suffolk University, the Neutron Research Project aims to investigate the neutron radiation energy of an americium-beryllium (AmBe) source located at Massachusetts General Hospital. Arrays of energy dependent bubble detectors are used to detect radiation in six energy ranges in order to construct a full radiation spectrum.

Proposal Statement

Overview of Proposed Project

The general aim of this project is to create a better understanding of neutron radiation and shielding effects of different materials. Due to the Earth's magnetosphere, cosmic radiation from the sun is somewhat deflected and humans on the surface are not subjected to the intense radiation they will receive on a long trip to Mars. Through a partnership with Massachusetts General Hospital (MGH), terrestrial neutron radiation sources, such as an AmBe source, can be used to study various shielding materials that could potentially be used to protect astronauts from neutron radiation resulting from cosmic ray interactions with walls of the spaceship. These effects are energy dependent so first the energy distribution of our neutron source must be determined.

The research project involves making several trips to the Proton Center at MGH where the AmBe source is located and transferring our bubble detectors and experimental apparatus to a collaborating physicist. Due to COVID-19 restrictions at the hospital, the research team of students is not allowed to enter, so the exposure of the detectors is done by our MGH collaborator. Afterwards, we collect the bubble detectors, take pictures for later bubble counting, recompress the detectors with apparatus obtained in a previous SPS grant for the 2019-2020 school year. Then, the analysis is completed to determine the activity of the source in different energy regions. Multiple trips to MGH are required because no more than about 100 bubbles can be successfully counted in a single bubble detector. As a result, one trip does not produce very good statistics.

As a result of the research, the activity of the AmBe source in 6 different energy regions from 0 to 20 MeV will be determined. This will be important for later studies of energy dependent shielding properties of different materials (e.g. polyethylene, water, plastic, etc). There is an important SPS connection because members of SPS become part of the Neutron Team and help with construction of apparatus, trips to MGH, data analysis, and write up of results. This forms the basis for trips of SPS members to an APS meeting to present results in a poster session and later to write up results for an article to be submitted to JURP.

Background for Proposed Project

This study of the neutrons emitted by an Americium- Beryllium (AmBe) source at the Proton Center at Massachusetts General Hospital (MGH) has been ongoing for several years. Currently, this research strives to answer a major question to allow our experiments to continue. The initial efforts were to measure the absorption of neutrons from the AmBe source by different thicknesses of polyethylene. This work produced clear results of the energy dependence as the layer of polyethylene increased. As lower energy neutrons were filtered out, the absorption coefficients of high energy neutrons in polyethylene that were obtained were consistent with published values. This work resulted in a JURP publication: "Neutron Radiation in Polyethylene Using an Ambe Source" in JURP, Volume XXVIV, Issue 1. The current efforts are centered around the energy distribution of the neutron source at MGH because the energy distribution varies from one AmBe source to the next. (Sommers, J., Jimenez, M., Adamic, M. et al., 2009) The energy distribution of the AmBe source at MGH is unknown, with proper techniques and analysis- this research will be able to determine the energy distribution and leverage that for future experiments.

Bubble detectors, made by BubbleTech in Canada, are transparent tubes (approximately the size of a test tube) that are filled with a gel which has the property of producing bubbles when a particular number of neutrons pass through. The devices are calibrated to a specific number of bubbles/mrem, so by counting the bubble after exposure the dose in mrem received by the detector can be calculated. From BubbleTech's calibration of the detectors, the conversion from mrem to n/cm^2 is known, through calculations the neutron fluence received by each detector can be determined for the time interval it was exposed.

The energy dependent detectors have different energy thresholds ranging from thermal to 20 MeV in increments at 10KeV, 100 KeV, 600 KeV, 1000, Kev, 2500 Kev, and 10,000. The analysis is somewhat complicated because the energy thresholds are not sharp and the cross sections in each energy window vary for any given detector. Fortunately, these are made available in a cross-section matrix from BubbleTech. Typical shelf-life for a detector is approximately three months if refrigerated after being properly recompressed by means of an RC-18 compression chamber. The result is that the continued experiments require a replenishment of the bubble detectors and form the bases of this grant proposal.

Expected Results

For this research, the main goal is to determine the energy distribution of the MGH AmBe neutron source. Additionally, a secondary goal is to begin experiments to learn how to characterize the neutron shielding effect of different thicknesses of polyethylene as a function of energy. This will then allow for the determination of linear attenuation coefficients as a function of energy for polyethylene and other materials. The determination of the energy distribution of the AmBe source is crucial for this work.

From previous experiments, it is expected that there will be some difficulties in extracting the activity of the source in different energy regions due to experimental error in the bubble counts. The results depend on solving 6 simultaneous linear equations with the constraint that the solutions be positive. A simple matrix inversion does not work, based on the experiments last year, because although mathematically correct, the matrix inversion produces non-physical negative results in some energy regions. The procedure to remedy this issue is explained below.

From experiments done last year, it was discovered that the backscattering of the neutrons from the table supporting the source and the detectors can be a problem. Additionally, an experimental design has been prepared to get around this problem. The end result will be the activity, with errors, of the AmBe source in the six different energy regions.

Description of Proposed Research - Methods, Design, and Procedures

Each of the bubble detectors were designed with a specific neutron energy threshold, meaning it will only produce a bubble if a neutron of higher energy passes through it. Before each experiment, time and distance calculations will be completed that produce estimates of how long it will take for each detector to be irradiated to contain about 100 bubbles. Keeping the bubble count around 100 bubbles is important because when there are greater than about 150 bubbles, it becomes increasingly difficult for students to accurately count them.

Currently, the Proton Center at MGH is restricting entry due to COVID-19 precautions and the research team is unable to enter the center to conduct the experiment hands-on. One of our physics collaborators at MGH, Joe McCormack, a cyclotron operator, will set up and run the experiment. The SPS chapter will walk to MGH , only a few blocks from Suffolk, to give him our bubble detectors, as well as go over the experiment with schematics showing placement of the detectors as described below. Hopefully, by Spring 2022, the research team will be able to enter the center again.

In the Proton Center, Joe will set up multiple detectors of varying energy thresholds on our apparatus, described below, that reduces neutron backscattering. Each detector will be marked carefully with the threshold number and its distance from the source.

After calculated intervals of time, the bubble detectors will be removed when he estimates them to contain roughly 100 bubbles. He removes the detector, records the time in which the detector was removed from the source, and continues with another detector in place. This process is repeated until all detectors have been exposed.

Then, the source will be taken away and he will call to let us know they are ready. The SPS chapter will walk back to MGH to pick them up. Once returned to Suffolk, photos will be taken of each detector at 90 degree angles. After ensuring all photos are uploaded safely to our research web page on BlackBoard (university LMS), the bubble detectors will be recompressed at about 500 psi for 20 minutes and then refrigerated for later use.

One problem which was discovered in an experiment last year was due to neutron backscattering. The research team had built a table of ½ inch plywood with markings from the center, where the neutron source would be placed, out to locations for the different detectors. Detectors with lower sensitivity (bubbles/mrem) were placed closer to the source so that after a certain amount of time all of the detectors would have about 100 bubbles. However, when the data was analyzed, the results indicated an activity level much higher than the known total activity of the source. When neutrons leave the source, they are emitted in all directions. The calculations assumed only neutrons in a straight line from the source could reach the detector to produce bubbles. However, the neutrons from the source in the downward direction could be scattered from the table and then go up and enter the bubble detectors producing an artificially high reading. To get around this, the research team constructed a unit with four posts, each about 18 inches high, in a rectangular array. The detectors will be placed into holders at the top of each post and the neutron source will be placed at the top of a stack of polyethylene blocks in the center of the post array and at the same height as the detectors. There is nothing in the downward direction from the source except polyethylene which is a good absorber of neutrons. This should solve the issue of artificially high readings.

Another interesting difficulty is that the analysis to determine activity in each energy window requires solving equations of the following form:

$$\begin{aligned}
\sigma_{11}f_1A_1 + \sigma_{12}f_2A_2 + \cdots \sigma_{16}f_6A_6 &= N_1 \\
\sigma_{21}f_1A_1 + \sigma_{22}f_2A_2 + \cdots \sigma_{26}f_6A_6 &= N_2 \\
\cdots \\
\sigma_{61}f_6A_1 + \sigma_{22}f_2A_2 + \cdots \sigma_{66}f_6A_6 &= N_6
\end{aligned}$$

The notation is such that the right-hand side consists of the number N of bubbles counted in each of the 6 bubble detectors. That number has a statistical error that equals the square root of the number

The other factors are as follows:

σ_{jk} = cross section from BubbleTech in bubbles/n.cm^{2}for the jth detector and the kth energy region
f_j= factor including distance of the jth detector from the source and exposure time
A_k= activity in n/sec of the source in the kth energy window

The solutions to the 6 equations are sensitive to changes in the numbers on the right-hand side. As a result, a constraint must be built into the solution that only positive solutions are allowed. To do this, different students write their own programs in Python and C++ to determine the best possible values for A_k such that the errors were minimized. This was done by originally assigning a random number to each activity and then calculating the predicted value of N_j for the jth detector. The error was then calculated as the sum of all the squared values of predicted minus actual measurements of the number of bubbles. Then, the activity was varied slightly to determine a new error and if the error was larger, then the activity was moved into the opposite direction. An iterative process was used to produce the final values. To test this, a system with known values in the equations was set up. Through this test, it was determined that the program produces the best values for a solution and this will be used with the data that is collected.

Plan for Carrying Out Proposed Project

The entirety of the SPS chapter takes part in the research project. About half of the students are juniors and seniors and have been working on this project since they came to Suffolk freshman year, they give the team the advantage of seeing the project in all iterations it has been through. All upper-level students have been trained on all aspects of the project, including instrumentation, data analysis, execution of experiments, and how to write research reports and posters.

In addition to the SPS members, Joe McCormack, cyclotron operator at MGH, Jacqueline Nyamwanda, Educational Coordinator for Medical Dosimetry at Suffolk University, Dr. Walter Johnson, Physics Program Director at Suffolk University and project leader, also participate in the research.

This project is in collaboration with Massachusetts General Hospital's Proton Center, where we have access to both the linear accelerator and AmBe radiation source. Typically, data analysis is done together in our physics laboratory on campus, however, COVID-19 has put a bit of a damper on that. To make up for our lost time on campus and in the lab, and not having access to MGH in person, the team has become familiar with working together both remotely and in VR. Most of the participating students also work and do research in the Multiple Realities lab on campus through various VR/AR technologies. Because of our familiarity with the Oculus Quest, and a recently discovered program called Spatial, we are able to meet through headsets in the virtual lab quite consistently. This was vital for us to be able to complete our research for the 2020-21 academic year; we will demonstrate to Jacqueline Nyamwanda and Joe McCormack (who both have access to the Proton Center and we work closely with) experimental procedure through 3D models and instructions posted in the virtual lab on Spatial.

Project Timeline

January 2022

- Begin planning for experiment execution and order detectors

February 2022 - March 2022

- Conduct several experiments at Mass General Hospital using the new detectors
- Recompress the Bubble detectors each week
- Submit results to JURP on March 15

April 2022

- Present at APS April in New York, New York, April 9-12, 2022.
- Continue recompressing bubble detectors

May 2022

- Submit interim report due May 31

June 2022 - August 2022

- Submit chapter report due June 15
- Typically there is no activity during the summer months

September 2022

- Train new students
- Begin planning for experiment execution

October 2022 - December 2022

- Plan for several experiments using detectors and compression system
- Submit final report on December 31

Budget Justification

The energy dependent bubble detectors are critical in order to create energy distribution for the neutron radiation coming from the sources. Individually, these detectors are not very expensive (about $160- see attached quote in spreadsheet). The expensive recompression system associated with these specific bubble detectors has already been purchased so this is a relatively inexpensive operating price. The biggest hurdle in performing research this year is the ongoing pandemic, because of this, students are not able to enter the hospital and any face-to-face interaction has to be kept to the barest minimum. These are not the optimal conditions to learn and produce quality research under, yet we are continuing to make the best of it.

Bibliography

Barbagallo, D., Bolduc, B., Hassett, B., Johnson, W., Koumba, K.,Leeming, A., Mach, P., McCormack, J., McDonough, M., and Nyamwanda, J. (2020). Neutron Attenuation in Polyethylene Using an AmBe Source. Journal Of Undergraduate Reports in Physics (JURP), Vol XXVIV, Issue 1, p. 36-40

Murata, I., Tsuda, I., Nakamura, R., Nakayama, S., Matsumoto, M., and Miyamaru, H. Prog. Nucl. Sci. Technol. 4, 345–348 (2014). https://doi.org/10.15669/pnst.4.345

Magalotti, N., Lacoste, V., Lebreton, L., and Gressier, V., Investigation of the neutron energy distribution of the IRSN 241Am–Be(α,n) source, Radiation Protection Dosimetry, Volume 125, Issue 1-4, July 2007, Pages 69–72, https://doi.org/10.1093/rpd/ncl537

Nolan, J., McDonough, M., and Thomas, J. (2018). Mapping the Neutron Flux Distribution Near a Medical LINAC.[online] Society of Physics Students.

Sommers, J., Jimenez, M., Adamic, M., Giglio J., and Carney, K. Characterization of a sealed Americium–Beryllium (AmBe) source by inductively coupled plasma mass spectrometry. J Radioanal Nucl Chem 282, 929 (2009). https://doi.org/10.1007/s10967-009-0189-1