SPS Chapter Research Award Proposal

Project Proposal Title	Neutron Production and Detection Techniques Around A 15 MeV Medical LINAC
Name of School	Suffolk University
SPS Chapter Number	6917
Total Amount Requested	$2000.00

Abstract

High purity metal foils may be used for activation analysis in the determination of the energy spectrum of a neutron energy flux. The objective of this research is to determine the neutron environment around a linear accelerator (LINAC) beam head used in oncology treatments at Massachusetts General Hospital (MGH). This investigation will use an NaI scintillation analyzer to observe beta and gamma decays emitted from the irradiated metal foils. It is expected from previous simulation and comparison of equipment that the neutron flux will be on the order of and a mean energy between 100 keV and 500 keV [1]. For successful completion of this experiment, a range of energy resonances for neutron absorption must be observed. A kit of high purity foils must be purchased to accomplish this. This research will benefit students as it increases understanding of nuclide reaction chains, and develops experience in the entire investigatory process including design, rehearsal, setup, all the way through statistical analysis of results.

Proposal Statement

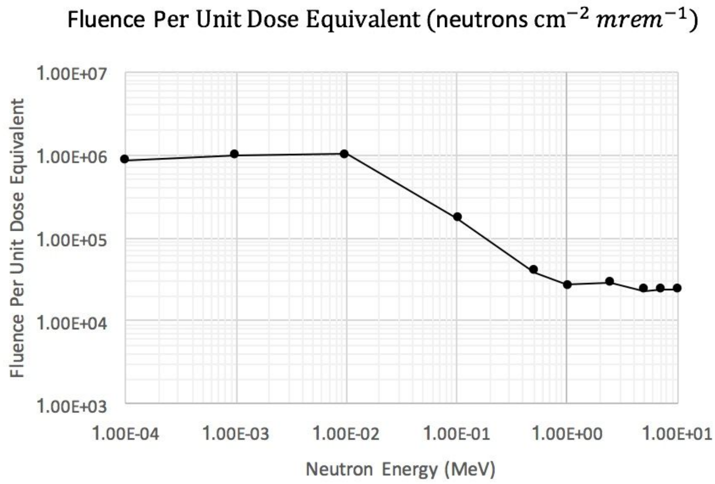
Overview of Proposed Project

The initial infrastructure of this research has been developed by two undergraduate students (and their advisor) at Suffolk University for their senior projects to identify the thermal neutron flux from a medical LINAC. To share this knowledge and experience, it is the students' goal to include as many undergraduate physics students (who happen to also be SPS members) as possible, and grow the research into a permanent investigation and training, which may eventually lead to a publication. The problem at hand is to determine the energy distribution of the neutrons emitted from the LINAC. In order to develop this into a research experience that fellow students may take ownership in, there must be a step taken forward from the senior project work alone. This involves using high purity metal foils to fully map the neutron energy spectrum of the medical LINAC, rather than just the thermal neutrons.

Background for Proposed Project

Moderate energy neutrons are found to cause the greatest damage to living tissue, due to their ability to induce proton recoil and gamma ray production [2]. The Varian Truebeam LINAC beam head produces a direct neutron fluence when photons that have been produced by electrons hitting a tungsten target interact with the machine equipment. Photons are attenuated with lead jaws of the beam head's collimator as well as other materials around the beam source, and create photoneutrons. These neutrons are defined as direct, radiate outward in all directions, and vary in part due to the makeup of material and equipment within the beam head [3]. Additional neutron production occurs when the photon beam exits the head and transports through a treatment room and interacts with matter.

This project began using sets of bubble detectors to measure the neutron production for neutrons above 200 keV and up to 15 MeV. These bubble detectors have been used in multiple experiments carried out by this research team, in order to determine the high energy neutron dose rate of the LINAC. The results of this experiment found a Neutron Source Strength of 4.1×10^11 neutrons/Gy, unfortunately this calculation is not for the entire neutron energy spectrum. Bubble detectors count effective dose rather than exact fluence, and the lower than 200 keV neutrons contribute in number the greatest quantity to the absorbed dose, as shown below.



National Regulatory Council [3]

The most recent trip to MGH involved two stages, the first stage was comprised of two separate runs. Run A was comprised of low sensitivity bubbles detectors and run B was comprised of medium sensitivity bubble detectors, each run used 6 detectors placed along a line aimed at the LINAC head. This setup allowed us to measure and show a 1/r^2 dependence of the neutron radiation. The second stage was a test to see the rate beta and gamma decays of a high purity metal foils. The results of the foil detectors showed a noticeable decay after one half life. In order to continue on with foil detection more foils are required to fill the full spectrum. The goal is to have a spectrum ranging from 0.025eV to 13.5MeV, this will give us the closest neutron source strength value that will account for all thermal and high energy neutrons produced by the LINAC.

Expected Results

It is expected that the spatial distribution of neutrons produced from a linac head will differ for different energy levels. Thermal neutrons are expected to be homogeneously distributed across the treatment room whereas epithermal neutron fluence reaches maximum around linac head, and fast neutron fluence decreases with the inverse square of distance from isocenter. Using such information, we can generate more inclusive maps of the neutron environment in the treatment for different settings and orientations of linac head. With these maps, assessment of neutron radiation shielding materials, such as polyethylene, effectiveness can be carried out in future experiments.

The neutron source strength value in neutrons / Gy of photon radiation has been characterized in other models of medical LINAC, such as the Varian 2100C/2300C. The mean energy was determined to be 0.45 MeV using a 15 MeV beam with the lead collimator closed to 0 cm x 0 cm. There is little research using this newer LINAC model, other than simulation, which does not provide a mean energy. In addition, methodology up until this point by this team has the lead collimator at a 10cm x 10cm photon beam area. For this reason, it is expected that if both models have identical designs, that our experiment will find a mean energy below 0.45 MeV, as less neutrons are being produced in the LINAC head from the highest energetic neutrons. In addition, this exact design is not likely, however determining the mean neutron energy is important for informing medical professionals how much radiation their patients are receiving for each LINAC model.

Description of Proposed Research - Methods, Design, and Procedures

- Meetings will be conducted with fellow students on how to determine the expected decay values for each of the foils.
- Finalize theoretical results for planned foil analysis
- Finish experimental design
- Conduct rehearsals at Suffolk University with fellow undergraduate students.
- Divide equipment among students for accountability
- Meet with Dr. Gierga at MGH
- Setup Equipment
- Irradiate Metal Foils: Here the LINAC is automatically cooled, however long periods of irradiation must be broken down into smaller periods of time. The means to calculate expected fluence values are described below.
- Disassemble Equipment and ensure accountability of equipment
- Observe for decays (time option 1)
- Return to Suffolk University
- Observe for decays (time option 2)
- Verify if results match with expected findings.

It is expected that not all foils will be able to be measured in the same trip to MGH. Multiple trips may be planned with the facility given with at least two weeks notice.

Mathematical Methods

The production constant of a material under a radiative flux of neutrons is shown by:

$$\lambda_A = \sigma_{A\rightarrow B}\ \phi_n \qquad (1)$$

Where $\sigma_{A\rightarrow B}$ is the neutron absorption cross section, and ϕ_n is the neutron flux. This flux value is the only unknown, as we will see soon that the production constant may be solved for and cross sections are known from tables and previous experiments. This equation represents the initial activity:

$$A_0 = Activity = \lambda_B N_B(t) = N_A(0)\lambda_A(1 - e^{-\lambda_B t}) \qquad (2)$$

λ_B is the decay constant of the new isotope, after neutron absorption and $N_A(0)$ is the initial number of atoms within the metal foil.

Finally, the decays will be observed not immediately after irradiation, therefore an additional decay time factor must be considered. As shown here the activity of new isotope B is:

$$A_B(t) = A_0\, e^{-\lambda_B(t-t_0)} \qquad (3)$$

The value $A_B(t)$ is the activity measured after any time t, where t_0 is the amount of time the foil went under irradiation. The above equations may be solved for the neutron flux ϕ_n as combining equations (1), (2), and (3) allow:

$$\phi_n = \frac{A_B(t)}{\sigma_{A\rightarrow B}\, N_A(0) \sum e^{(-\lambda_B t_j)} - e^{(-\lambda_B t_k)}} \qquad (4)$$

Due to our procedure where we must irradiate for long increments with breaks, in order to prevent overheating of the LINAC. The summation in the equation above takes account for the irradiation times (t_j) and break times (t_k).

Plan for Carrying Out Proposed Project

This project will require the collaboration of several students as well as a well-informed and capable faculty team. Our team involves eight undergraduate physics students including: Jackson Nolan, John Thomas, Telvin Benjamin, Eric Bergstrom, Molly McDonough, and Mario Rojas. All of whom will be providing support throughout the project and are currently SPS members. Paul Johnson and Allen Alfadhel are two students working on their senior projects to determine the thermal neutron fluence coming from the LINAC beam head.

The space for this research has been provided by MGH which has allowed our group to use a radiation therapy room after treatment hours to study the byproduct neutron radiation generated by their LINAC beam. While the experiments will be conducted at MGH, all further analysis and workup of the data will be carried out on our main campus in our very own Nanoscience Laboratory.

Faculty supervisors of this project are:

- Dr. Walter Johnson is the primary investigator in this research.
- Dr. David Gierga is the Program Director of the Harvard Medical Physics Residency Program and a senior scientist with MGH, and professor at Suffolk University
- Jacqueline A. Nyamwanda is a member of the Department of Radiation Oncology with MGH and a close collaborator with Suffolk university whose affiliation to both institutions has been instrumental for the project.

Project Timeline

The following timeline is to show that experience has been gained over the past months in foil activation analysis of thermal neutrons absorbed by metals, and the future direction of the research. Note: The research up until this point includes 2 members of the chapter’s SPS executive board, and a SPS member. The future research will include all members in the planning and analysis process. If a date has passed that is shown below, it has been completed. Dates not yet passed are proposed “no later than” completion dates.

Fall Semester 2017

1. Purchase of thermal neutron foils: Completed 10OCT17.
2. Calculate expected activity values based on other neutron source strength of Varian LINAC model: For thermal neutrons completed 20OCT17.
3. Irradiation of foils with-out Cd filters completed for thermal neutrons to gain experience with gamma detection equipment: Completed once 23OCT17, ongoing.
4. Observe Activity: Tested once with thermal neutrons and gamma detection using NaI crystal scintillator. Completed once 1NOV17, ongoing.
5. Conduct results driven experiment for thermal neutron activation using current foils and conduct test run and evaluation using broad energy spectrum foils to gain experience. 15DEC17
6. Purchase of fast neutron detection kit (Funding Required) 31DEC17

Spring Semester 2018

7. With broad energy spectrum foils, calculate expected activities. 15FEB18
8. Plan details of experimental setup in LINAC treatment room for broad energy spectrum foil activation analysis. 1MAR18
9. Irradiate foils with neutrons and conduct beta and gamma detection 15MAR18
10. Complete analysis of data with SPS team of all thermal and fast (broad spectrum) data. 1MAY18
11. Complete initial paper with results 1JUNE18

Budget Justification

The Suffolk University Physics Department has covered the funding for the purely thermal neutron analysis up until this point. To conduct a broad spectrum analysis, a kit from the company Shieldwerx may be purchased that includes 4x metal foils of each of the following: Al, Cu, Au, Fe, In, Mg, Ni, Sc, Ti, V, and Zr. These foils are all 12.7 mm in diameter. This company has provided the department with the other thermal neutron detection foils.

This broad spectrum kit also includes 10 cadmium covers that are used during the experimental process to exclude thermal neutrons. Having the 4 foils per element allows for irradiation using cadmium, and without cadmium in the same experiment, reducing errors. This set of foils enables analysis of both resonance and threshold absorptions (depending on the reaction chain type) ranging from neutron energies of 0.025 eV to 13.5 MeV. Though the department has already purchased two foils that detect the thermal energy, it only has a maximum thermal neutron energy detection of 0.4 eV, the cadmium "cutoff" energy, where the cadmium covers are used.

The Shieldwerx neutron activation foils that cover the broad energy spectrum have a total cost of $2250. The chapter is proposing that if the SPS can assist up to the limit they are able, the university physics department paying for the rest of funding of $250.

Bibliography

[1] Kim H.S., Park Y.H., Koo B.C., Kwon J.W., Lee J.S., Choi H.S. Evaluation of the photoneutron field produced in a medical linear accelerator. Radiat Prot Dosimetry. 2007;123:323–328.

[2]Table 20.1004 Units of radiation dose. (n.d.). In *NRC Regulations (10 CFR)*. Retrieved from https://www.nrc.gov/reading-rm/doc-collections/cfr/part020/part020-1004.html#N_2_201004

[3] Varian Medical Systems, PhD, FACR, FAAPM. (2017, January). *TrueBeam IEC accompanying documents type tests* (Technical Report No. P1012903-002-B). Palo Alto, CA: Varian Medical Systems.