SOCIETY OF PHYSICS STUDENTS
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SPS Chapter Research Award Interim Report

Project Title	Neutron Production and Detection Techniques Around A 15 MeV Medical LINAC
Name of School	Suffolk University
SPS Chapter Number	6917
Total Amount Awarded	2000
Project Leader	Walter Johnson

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 2*10^4 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.

Statement of Activity

Interim Assessment

- Research question – What question does the research aim to address?

What is the total neutron flux near a 15 Megavolt (MV) Linear Accelerator (LINAC) used in oncology treatments? What is the neutron flux for the 15 MV machine in different energy regions?

- Brief description of project – What has the research project entailed, and have new elements influenced the overall aim of the research?

This research project has been conducted using multiple high purity metal foils which were irradiated using a 15 MV Varian TruBeam LINAC at Massachusetts General Hospital. Once these foils were irradiated they were then taken to a liquid beta scintillator where the beta decays for each foil were measured. Using the activity of the beta decays, we could determine the number of neutron activated nuclides in the foil and from that, the neutron fluence which produced the activation. From our previous work with bubble detectors, we were able to determine the flux for neutrons above 200 keV, but the bubble detectors are not sensitive to lower energy neutrons. The foils allow us to to determine the neutron flux in the lower energy region for thermal and epithermal neutrons. Different foils are needed for different low energy neutrons due to strong energy dependent variation in the neutron absorption cross section for different metals. With this we were then able to calculate the epithermal and total neutron flux of the LINAC. With our current materials we have seen positive results based on our procedure and with new foils we aim to continue this process so we can build a better energy spectrum for the neutron production of the LINAC.

- Progress on research goals – What has been accomplished so far?

We have run an experiment using both indium and gold foils. This experiment was designed to determine the thermal neutron flux of the LINAC which is calculated using two separate foils, one covered with cadmium and one without cadmium. Due to the very high cross section of cadmium for thermal neutrons, the foil with cadmium covers would receive only neutrons above the thermal energy (0.025 eV). This allows us to have one foil that that when irradiated receives both thermal and higher energy neutrons and one that receives only the higher energy neutrons. By subtracting the flux of one foil from the other we can determine the thermal energy flux and the higher energy flux. Gold and indium have strong resonance cross sections just above thermal energy (epithermal), which allows us to determine neutron flux dominantly in the energy window of the resonance. This process was done using both gold and indium foils.

- Any changes in the scope of project – Indicate whether the project is turning out to be a more complicated or more straightforward than expected and why; influencing factors may include personnel size, research scope, materials and equipment availability…

The scope of the project has remained the same, in that, we aim to determine the full neutron energy spectrum in order to determine the true neutron source strength. This has become increasingly more difficult as we have been basing our calculations on the mean beta energy which is how we have determined our mass and thickness correction factors. As we continue on we aim to calculate this correction factor using the full energy distribution for the beta instead of just the mean energy, which could potentially change the correction factors and ultimately the calculated thermal flux.

- Personnel – Who has been involved in the research activities and in what ways? How many participants are SPS members?

We have been working with Dr. David Gierga, a Medical Physicist at MGH and an Assistant Professor at Harvard University, Tara Medich, the Associate Director of Radiation Safety at MGH, Jacqueline Nyamwanda, Educational Coordinator for Medical Dosimetry at Suffolk University, Dr. Walter Johnson, Professor in the Physics Department and Project Leader, as well as ten active SPS members, four of whom are the executive board.

- SPS connection – How is the activity strengthening the objectives of the SPS program, both at the proposing school and nationally?

This project has given us a chance not only to pursue our own research questions, but also as a chance to show that even though we are a small department we are able to compete with the top schools in our area. Being a small department in a school that does not focus on science and in the middle of Boston, surrounded by some of the greatest schools, we are able to put Suffolk University on the map as a school that is on the driving edge of research. This project through SPS has given us as students the chance to participate in research that is being done on the graduate level and have hands on experience with equipment that most universities do not have. This project has given us the chance to use a medical linear accelerator as our own neutron source to understand how neutrons interact in an effort to work towards designing materials that can be used for neutron shielding. Neutron shielding is one of the hardest issues to solve in creating safe travel to mars and with our research we able to work towards solving this universal problem.

This project was presented during the APS April Meeting in Columbus Ohio during the graduate research poster session. Members of our team presented the poster to many universities that were conducting similar projects and the manager of the research office of the Australian Nuclear Science and Technology Organization at the DINGO neutron imaging site, was impressed by our research and has offered time at his imaging site to conduct future projects. All of this is because of the grant we have received through SPS and during our poster presentation we included the SPS logo in the header of our poster to promote the research that SPS funds.

Updated Background for Proposed Project

This section should be a supplemental update to the background given in the project proposal. Indicate any new literary sources being used and include a brief summary of relevant research that has been newly published or that has been newly uncovered or applied by the researchers. If appropriate, provide an updated explanation of how the research project will contribute to the scientific discussion.

During our previous experiments we were using two sets of copper foils where one of the sets was twice the thickness of the other set. We carried out our experiment with the assumption that since the foils were twice the thickness we therefore we would expect to see twice the number of beta emissions. This was not the case however, we found that between both sets of copper foils we were receiving about the same number of betas emitted. With further investigation we found that for each isotope the energy of the beta emitted determines how far it will penetrate. For our calculations we are considering the mean beta energy and defining it as s and the thickness of the foil t. Each isotope of a material has a beta range range that falls into one of three conditions; 1) $s<t/2$, 2) $t/2<s<t$, or 3) $t<s$. For copper 64, the beta range is in condition 1, meaning that even though the foil is twice the thickness, the emitted betas are only escaping the top layer and the bottom if the leaving out the top or bottom respectively. This correction factor was not taken into account during our initial experiments but were taken into account during our most recent experiment using indium and gold. For indium and gold the beta range fell into range two where $t/2<s<t$.

Description of Research - Methods, Design, and Procedures

In our most recent experiment we used a wooden array with the metal foils placed in paper holders that were then fixed to the wooden arms, this allowed us to ensure that the foils would not move as well as have the most surface are possible facing the head of the LINAC. In the array we had four indium, four gold, and three copper foils. Two indium and two gold foils were covered in cadmium and two indium and two gold foils were left uncovered. The three copper foils were all left uncovered and one copper foil was perpendicular to the head of the machine. The array can be seen below in *Figure 1.* The foils were then irradiated for 30 minutes after which they were then brought down to a liquid beta scintillator were we placed six foils in the cassette, two indium, two gold, two copper, and one blank vial for background detection. We ran this cassette once then placed the two more indium and two more gold foils into the cassette to run cycling through night measuring each foil for fifteen minutes. We proceeded to leave for the night and returned in the morning after the fourth cycle was complete.

Figure 1

Initial Results

Using the total number of decays measured by the beta detector and the correction factor, C_f, for a foil that has a beta energy range that is greater than half the thickness of the foil but less than the full thickness of the foil, we have :

$$N_{tot} = C_f N_{out} \text{ where, } C_f = \frac{1}{\frac{3}{2}(g-1)+\frac{1}{2g}} \text{ and } g = \frac{\text{range of betas}}{\text{thickness of foil}}$$

The total beta count was calculated for each foil at each time of detection through the night allowing us to determine the thermal neutron flux, I_{Th}. In order to calculate this we first needed to determine the resonance (epithermal) neutron flux, I_{Res}, and the total neutron flux, I_{tot}, where; λ_b is the decay constant of the isotope, N_a is the number of isotope nuclei, t is the irradiation time, r is the rest time, m is the measurement time, CPM is the counts per minute counted during m counted by the beta scintillator, BGC is the background counts per minute of the beta scintillator, the efficiency is the 3H efficiency of the beta scintillator, and σ is the cross section of the isotope of activation.

$$I_{tot} = \frac{Decays*\lambda_b}{N_a*\sigma(1-e^{(-\lambda_b*t)})(e^{(-\lambda_b*r)})(1-e^{(-\lambda_b*m)})}$$

$$Decays = \frac{(CPM-BGC)Observed\ time*C_f}{efficiency}$$

$$\sigma = 2*\sigma_{Th} + \sigma_{Res}$$

$$I_{tot} = I_{Th} + I_{Res}$$

For our case, I_{tot}, was determined using the foils that were uncovered as they received the full possible number of neutrons. Due to the properties of thermal neutrons, the total cross section must take into account the thermal cross section twice because thermal neutrons enter from both sides of the foil as they bounce around the room, where as the epithermal neutrons only enter from the face directly facing the machine and as they travel around the room they thermalize. When calculating the epithermal flux the foils that were covered in cadmium were used because the thermal cross section is incredibly large and the resonance cross section is extremely low, meaning that only the epithermal neutrons will pass through the cadmium and irradiate the foil, meaning the cross section used in the calculations does not include the thermal cross section. Using these two values, the thermal neutron flux was determined for indium to be $2.707 \pm 0.574 * 10^4 \frac{neutrons}{cm^2 Gy}$ and for gold to be $1.594 \pm 0.205 * 10^4 \frac{neutrons}{cm^2 Gy}$. These values are close to published data on an older machine which said to be about $2.0 * 10^4 \frac{neutrons}{cm^2 Gy}$.

Statement of Next Steps

Plan for Carrying Out Remainder of Project (including Timeline)

This section should detail an updated plan for carrying out the remaining components of the project, in bullet or paragraph form. Include, at minimum:

- The key milestones and the dates by which important steps need to be completed in order to finish the project on time (by December 31).
- Personnel - Who will be involved in the remaining research activities and in what way? How many participants are likely to be SPS members? Are there SPS members or others with special expertise that will help to ensure success?

The research materials described above were purchased using both the initial funds provided by the grant as well as funds provided by the department. The total cost of the foils purchased was $1232, where the extra $232 was provided by the Physics Department to cover the full cost of the first set of foils.

- July 1 - Use energy spectrum for beta particles instead of mean energies to improve correction factors for betas we measure to those actually emitted. Use the corrections to recalculate gold and indium results.
- July 15 - Use existing procedures to study tungsten and dysprosium foils (which we already have). Also measure indium and gold to determine 1/r^2 dependence.
- August 1 - Order new foils based on resonance cross sections in different energy windows.
- September 15 - Run experiment on new foils to determine thermal and different energy windows for epithermal neutrons.
- October 15 - Measure neutron absorption in lightweight shielding materials (standard and borated polyethylene) for space applications using our known neutron flux at various distances from the beam head of the LINAC.
- November 15 - write up final report.

Personnel: Our team will be made up of four seniors, one junior, four sophomores, and unknown incoming freshmen as well as Dr. Johnson, Dr. Gierga, Jacky Nyamwanda, and Tara Medich. The senior students will continue to take on leadership roles in designing experimental setups and procedures while working with the underclassmen to train them in understanding the experiment and analysis of the data. The current upperclassmen have been a part of this project since the beginning and have gathered a wealth of knowledge in all of the aspects of the project and will take individual components to specialize in and train sets of students to that one topic, such as; experimental design, analysis, or simulations. This will allow each upperclassmen the chance to focus on a specific aspect of the project and lighten the workload for each other as they will no longer need to focus on all aspects of the research.

Bibliography

Liu, Wen-Shan & Changlai, Sheng-Pin & Pan, Lung-Kwang & Tseng, Hsien-Chun & Chen, Chien-Yi. (2011). “Thermal neutron fluence in a treatment room with a Varian linear accelerator at a medical university hospital”. Radiation Physics and Chemistry. 80. 917–922. 10.1016/j.radphyschem.2011.03.022.