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Summary of Internship Experience for 2010 DHS/ORISE summer program

E. Pusateri, MA Descalle

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Elise Pusateri – DHS Summer Intern 2010 LLNL

Project: Improving Image Contrast With an Energy Threshold - A MCNP Study

The U.S. Department of Homeland Security has deemed as a threat to national security the possibility of fissionable materials being concealed in intermodal cargo containers. Detecting these materials is critical to preventing nuclear proliferation and terrorism. Thus, several high-energy photon-based imaging applications are being developed to detect materials with $Z>72$ in such containers. In an initial study, an array made of plastic scintillator material was considered for a detector in combination with a bremsstrahlung source~~s~~.[1] While plastic is a practical and cheap material to use, it has relatively poor energy resolution. When studying the full spectrum of available materials, $Bi_4Ge_3O_{12}$ (BGO)[2] was considered and was eventually chosen as the scintillation material for its high mass density which permits high spatial resolution with reasonable detection efficiency. The final geometry of the detector chosen by UC Berkeley and Lawrence Livermore National Laboratory was an 8-by-8 array of 0.5-cm-by-0.5-cm-by-5-cm $Bi_4Ge_3O_{12}$ (BGO) crystals, with pixels shielded by 1-mm of lead. The purpose of my research was to model the detector response using MCNP, a Monte Carlo[3] code to demonstrate its expected sensitivity and ability to generate images, under conditions that could be tested experimentally and to determine the lowest energy threshold applicable.

The geometry chosen for study was an isotropic point source of 2.614-MeV photons, a detailed model of the detector, and, either a void, a 1.27-cm radius tungsten alloy sphere with a density of 18.57g/cm^3, or a water-filled 50-cm-by-50-cm-by-50-cm pseudo-cargo container with and without the tungsten sphere immersed in the center, located between the source and the detector. Eight by eight pixel images of the total counts in the 64 crystals were generated with MATLAB. For each image, four user-defined energy thresholds were applied, and the maximum count variation was estimated as a function of threshold.

In the void case, the counts differed by a factor of 1.15, mostly due to escape from the outer pixels. For the tungsten sphere images, the counts differed by a factor of 2.25, with the lowest counts being in the pixels shadowed by the sphere. For thresholds from 1 to 2.5 MeV, the counts differed by factors of 3 to 7, but the number of events decreased by a factor of 10. Images of the water-filled pseudo-container had counts differing by a factor of 1.82. For thresholds of 1 to 2.5 MeV, counts differed by factors of 1.03 to 1.09. With the tungsten sphere added, the images had counts differing by a factor of 2.25. For thresholds of 1 to 2.5 MeV, counts differed by factors of 2.12 to 4.5, also reducing the number of events by a factor of 10. By comparing the latter two simulations, it was concluded that the threshold could be set as low as 1.5-2 MeV.

These results indicated that, for the BGO detector, energy threshold could be applied to improve image contrast for fairly small, high-Z objects despite the loss of signal. This means that without compromising the statistics of the detector, we could find a small amount fissionable material in cargo by using an energy discriminator. The results will soon be compared to ongoing experiments performed at UC Berkeley, which will ultimately confirm or deny their validity. I then applied the Gaussian Broadening function in MCNP to smooth out the spectra created from the output of the pulse height tally assuming an energy resolution of 10 and 25% at 662 keV, therefore obtaining more realistic simulations of the detector response. This is very important because when the group at UC Berkeley obtains spectra from the simulations they run, they will have a clearer basis for what they should expect to be read out of the detector. Interestingly, the loss of resolution did not impact the energy threshold previously determined.

In terms of my accomplishments during this internship at LLNL, my results were summarized in a scientific abstract, two technical presentations, and a technical poster.

I developed a MCNP model of the BGO array fabricated by St Gobain, and models of several experiments. These models will be used for further simulations and comparison to experiments. I wrote qualitative and quantitative post-processing tools in MATLAB, to estimate the energy threshold applicable in an ideal "BGO array" and with defined energy resolutions. These contributed to the project milestone of characterizing the detector.

Throughout this internship, I made trips to UC Berkeley to present my findings. After giving a powerpoint presentation, I would discuss my results with the group, and they would give me feedback and suggest more areas that I could look into, such as adding a pseudo-cargo container to my geometry or using Gaussian broadening to make the response of my simulated detector more realistic. They would explain why I needed to make these changes and how it was going to help their experimental research. This was very helpful because it gave me a clearer idea of the purpose of my research and why it was important. It also helped me to see how everything was coming together in a larger context.

My research greatly contributed to my education because I have vastly improved my understanding of MCNP and the physics behind it. The research I've done here for twelve weeks has been invaluable. At RPI, the university I am attending for an undergraduate nuclear engineering degree, most of my work involving MCNP has been part of group projects. Because my natural strengths lie in mathematical and presentation skills, I wasn't involved with developing code as much as some of the more computational adept students. I've spent some time looking back on previous MCNP projects I've been a part of, and I can't believe how simple I find the MCNP work to be now. I have so much more confidence to complete projects using MCNP, and I'm looking forward to surprising my peers with what I've learned over the summer. This confidence also expands to research that I could participate in during my senior year, because many projects involve computational research and the use of MCNP. I feel that there are so many new options available to me because of the new abilities I've acquired due to my summer research for DHS.

This internship heavily influenced my academic planning. Before I came to LLNL, I applied for a co-terminal Masters Program at Rensselear Polytechnic Institute. I was somewhat tentative about pursuing a Masters degree, and I was strongly considering working for a couple of years, and paying off some student loans, before going back to school to obtain an advanced degree. There were major factors that changed my mind about this, and made me realize that the best option for me is to pursue my PHD in nuclear engineering immediately.

Most importantly, the group at Berkeley, including my advisors Marie-Anne Descalle and Dr. Stan Prussin, provided me much insight into what it would be like to be a graduate student, and how beneficial it would be to me to obtain my PHD immediately. Seeing the work that Marie-Anne has done and the extent of her expertise has been inspiring. Her drive and problem solving ability has taught me so much about the dedication it takes to solve a problem in the research field, and how much I can learn from making mistakes. There were times where I had to use very advanced level coding in MCNP or had to understand physics that I yet had not learned in school. Marie-Anne taught me how to use available resources, such as manuals and technical journals, and how to approach problems from different perspectives. Marie-Anne is a rare and admirable female role model. Besides her vast expertise, she balances her career, family, and a healthy life style with constant poise and professionalism.

She makes me realize, that with hard work and dedication, I can achieve any goal.

Also, Dr. Stan Prussin, the principle investigator of this detector project, often took some time out to talk to me about my research and my future plans. He provided much insight into the various fields that I could pursue, including industry, government, and education. After meeting with him, and the UC Berkeley Group, I am hoping that UC Berkley could be the place where I can pursue my PHD. The environment here is productive and engaging, and offers vast opportunities in the field of nuclear engineering.

In addition, doing research in nuclear engineering for the Department of Homeland Security has been such an honorable mission. I live in New York and viewed the horror and sorrow endured by many Long Island families after 9-11. To participate in a project that could improve our national security is an opportunity that is humbling. I feel I worked on something so valuable and greater than myself. Millions of cargo containers enter US ports every year. This project will enable us to insure that the cargo containers are not carrying clandestine fissile material. Using a photon-based radiographic technique to scan each cargo container, within a minute or less, would allow port authorities to identify suspect containers without disturbing the flow of commerce. I'm convinced that I will need an advanced engineering degree to further contribute to this kind of project.

Finally, the Wednesday lecture series conducted at LLNL was instrumental in my decision to pursue a PHD immediately. There are so many different projects, covering the full spectrum of different sciences. I became even more convinced that there are various projects that would interest and challenge me. Working in the field of nuclear engineering provides a lot a freedom to go into different areas of science, and as I watched all of the presentations, I could see myself working on many assorted projects, and contributing in a proactive way. This included Brooke Buddemeier's lecture on emergency management. In case of a nuclear attack, which I learned would most likely be caused by a dirty bomb, we need to have an evacuation plan in place. I learned to stay indoors incase of an emergency and to stay in the middle of a building. This research looked so interesting and it was clear that it could benefit millions of people. The threat of terrorism in the world today is extremely high and being prepared is a necessity. I learned that most people know what to due in case of a natural disaster, such as a tornado or hurricane, but the same people have no idea what to do in case of nuclear or biological threats, In listening to the lecture, I realized I could find a research area that could benefit humanity.

In conclusion, this internship was productive and fulfilling. Marie-Anne Descalle has been a mentor and a role-model, who helped me learn how to be a better researcher by asking my own questions and finding my own answers. Also, Dr. Stan Prussin, was very motivational and gave me the initiative to pursue graduate schools immediately, and start looking for areas of research I would find interesting. The research here was challenging and engaging, ultimately giving me a new perspective on what goals I want to pursue now, and in the future.

References:

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