The Effects of the Urban Environment on Background Neutron Flux

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Abstract:

This project will measure the neutron background in an urban environment using United States Naval Academy's (USNAs) high sensitivity neutron detection system, called the Large Neutron Sensor (LNS). The background neutron flux represents noise and affects our ability to identify a signal from illicit source material, including plutonium. As the neutron background essentially rains down from high energy cosmic ray events in our upper atmosphere, the shielding effect of skyscrapers in an urban environment on the ground level background is of interest. With a characterization of the neutron background in this environment, end users will be able to optimize the effectiveness of survey protocols and alarm algorithms.

1. Introduction and Experimental Plan

As the nuclear industry continues to grow across the world, and as terrorist and rogue militant groups increase their technical competence, there is an increasing threat of the use of nuclear and radiological material in conjunction with conventional or improvised nuclear bombs. The appeal to a terrorist organization of utilizing such material lies not only in an increased capacity to cause damage, but in causing widespread fear as a “nuclear terrorist”[1]. The current techniques used to prevent such an event in a populated city have been successful to date but the responsible parties (including the U.S. Department of Homeland Security and state and local law enforcement) recognize the need for continuous improvement [2,3]. Improving our ability to interdict includes improving personnel training, the effectiveness of equipment, the effectiveness of survey and scanning protocols, and the effectiveness of algorithms used to analyze signals and distinguish threat sources in a radiation background. This project addresses the latter capability; the goal of this research is to use highly sensitive neutron detectors to measure and characterize the effects of the urban environment on the background neutron flux to support the development and optimization of alarm algorithms for a higher likelihood of nuclear material detection in this environment.

Neutron sources are of interest in homeland security scanning because weapons-grade plutonium is 6% ^{240}Pu, an isotope that emits neutrons through spontaneous fission [4]. Because the neutron background originates in the atmosphere and results from cosmic ray interactions, it is primarily downward directed, especially for those neutrons at high energies. This fact suggests that tall structures may interfere with the adjacent ground level neutron background. The goals of this research are to (1) use portable, highly sensitive neutron detecting equipment in different urban areas in order to accurately characterize the shielding effect of structures on the background neutron flux and (2), conduct simulations of the measurements in order to better understand the angular dependence of those neutrons that are measurable by homeland security equipment. The terrestrial neutron flux due to cosmic radiation has been studied for nearly a century [2] but there is still information that can be learned about this phenomenon, particularly with respect to surveys conducted in the homeland security environment. For example, while the angular distribution of neutrons from cosmic particle interactions has been shown in several different studies [3], the results of these studies are not entirely consistent and a broad range of angular distributions have been proposed. Additionally, these studies have determined angular distributions at high neutron energies, and detector efficiency is energy dependent, so the studies may not directly apply to the response of systems used in homeland security. As seen in Table 1, the results for multiple independent studies at sea level show variation in angular distribution, even for the same neutron energy.

Table 1: Angular Distributions of cosmic Neutrons based on Neutron Energy

Neutron Energy (MeV)	Angular distribution	Citation
200	$\cos^3$	[9]
>350	$\cos^1$ to $\cos^4$	[10]
100-1000	$\cos^3$ to $\cos^5$	[11]
200	$\cos^{3.5}$	[12]
60-750	$\cos^{2.1}$ to $\cos^{2.6}$	[13]
10-100	$\cos^3$	[14]

Furthermore, the effect of the angular distribution on the neutron background in an urban environment has not been provided in open literature. Full understanding and characterization of spatial neutron flux is essential to ensure the most effective alarm algorithms are applied with the equipment used. For the purposes of this work, the urban environment includes areas where a significant portion of the sky is obscured by buildings, including downtown areas surrounded by skyscrapers. While it is known that the background neutron flux is dependent on environmental and geographic factors [4,5], this current research will quantify the effect of buildings on neutron background for detection systems of interest in the homeland security environment. Previous work has been conducted to show the significant effect of large structures on neutron background at a stadium [6]. Other studies have shown the significant changes in neutron background that are seen in the vicinity of ships at sea [7].

This work will employ the Naval Academy's Large Neutron Sensor (LNS) to conduct static neutron background surveys at specific locations such as the Thomas Jefferson Building in Washington D.C. or buildings within Baltimore City in order to characterize the shielding effect of buildings on background neutron flux in the urban environment. Initially, multiple static samples will be taken outside of the cityscape to establish baseline readings representative of background neutron flux unobstructed by buildings. After this initial measurement, the LNS will be moved to its predetermined locations within the city to obtain further readings. The data will be collected and compared to determine any statistically significant changes within the sample area.

Figure 1: Naval Academy's Large Neutron Sensor

Figure 1 shows the LNS, which consists of four seven-foot-long and six-inch diameter moderated tubes of pressurized ^{3}He (nearly 200 liters of ^{3}He). With this large sensor, count values on the order of 10,000 total counts are achievable in less than 10 minutes and data can be retrieved with a laptop computer through a USB connection. The reason this experiment needs to be conducted by USNA is due to the high sensitivity of the LNS, where the spatial characterization will be based on statistics that are not achievable with other laboratory or actual operational systems, so the data may even be revealing to experienced operators who routinely conduct surveys in urban environments [8]. Having a reliable understanding of the background neutron flux in an urban environment is important to any survey effort where additional source material is sought. For example, where neutron detectors are used to search for illicit nuclear material out of regulatory control, the naturally occurring neutron background must first be well understood in order to distinguish a change in radiation signatures. A typical alarm algorithm may involve set tolerances or threshold count levels where an alarm will be triggered above that level. To be effective, alarm levels need to be set high enough to avoid excessive alarms caused by natural fluctuations in radiation background, but low enough to ensure sensitivity to anticipated material and encounter scenarios. If a survey system has an alarm algorithm based on a simple and fixed threshold, and the background level changes, then the sensitivity of the system will also change. For example, if the background neutron flux drops significantly due to the shielding effect of structures like tall buildings, the alarm threshold will only be reached with an increased contribution from source material; or an otherwise detectable source could be transported through a survey area without exceeding the threshold and pass undetected. The specific deliverables of this research will provide evidence of whether current means of detection are optimized/reliable or not through accurately characterizing the variation in the neutron flux in the urban environment.

The neutron shielding effect of concrete buildings has been shown [4]. This phenomenon, combined with the angular distribution of the high energy cosmic neutron backgrounds, suggests that urban environments may show multiple different neutron backgrounds with varying obscuration of the sky. Past research has shown that eight inches of concrete created notable differences in neutron flux [5]. Therefore, it is reasonable to conclude that with the incoming angular distribution around vertical, multiple story structures in large cities will provide significant shielding effects for neutron flux. The results will be compared with the current radiation survey techniques employed by federal, state, and local government agencies in order to conclude whether or not the current methods are sufficient or if there are weaknesses in our current urban survey operations. Following the surveys, modeling will be conducted using the Monte Carlo N-Particle (MCNP) [18] radiation transport code. The angular dependence of the source term will be adjusted in the model until simulations match the variations seen in recorded data, and this operationally relevant angular distribution along with the quantified description of the spatially dependent neutron background in the urban environment is another deliverable for this project. Together, this information will be provided to the radiation scanning community for use in optimizing both neutron survey protocols in the urban environment and alarm algorithms used for urban surveys.

2. Preliminary Results

The LNS was moved to Baltimore on March 28th, 2018, for several static tests at predetermined locations. Figure 2 has a satellite image superimposed with the estimated data collection points in Baltimore for the preliminary testing. The green dot on top of the parking garage in the upper right is where the background neutron flux measurement was taken. The pink dot denotes the initial test, and the red dots are the subsequent static test in sequential order.

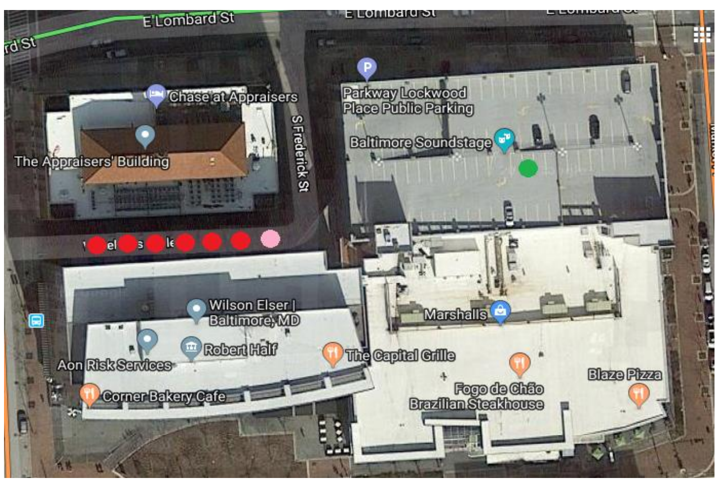

Figure 2: Baltimore Testing Site

Distances between and from buildings were measured with a laser range finder. The Appraiser's building (Top) was measured showing a height of roughly 34 meters, and the Wilson Elser building (Bottom) was measured showing a height of roughly 48 meters. Figure 3 shows how neutron flux varied based on distance from the Parkway Lockwood Place Public Parking garage averaged over ten-minute static test.

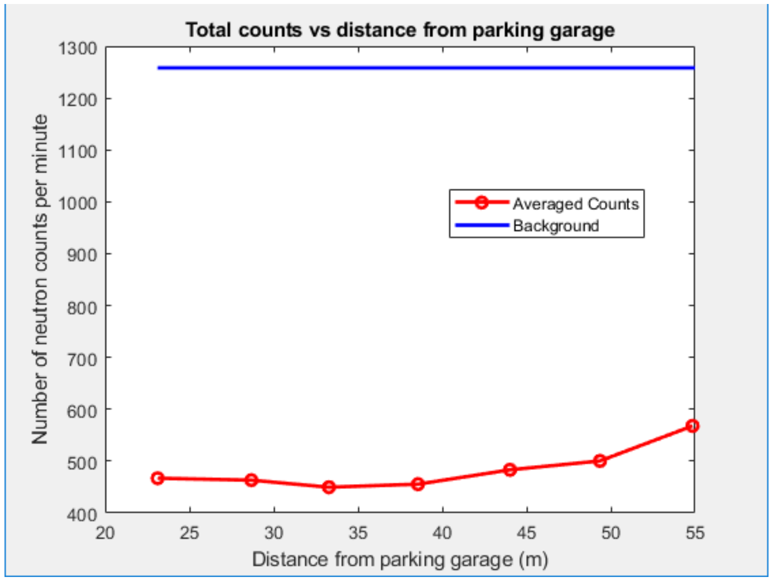

Figure 3: Total Counts over Duration of Experiment

As the distance from the parking garage increased, the average number of counts increased. Note that the area at the right side of Figure 3 (furthest from the parking garage) is unobscured by buildings. There was a significant decrease in neutron counts between the background readings and the readings between the two buildings as well.

3. Conclusion

Preliminary research has shown a consistent and significant increase in background neutron flux as the LNS became less obscured by the buildings, which suggests that the angular distribution of neutron flux causes background changes at the ground level in the vicinity of buildings. Should a detector be set to a specific threshold and not anticipate the drop caused by the urban environment, source material out of regulatory control may go undetected. This project will conduct static neutron surveys in several representative urban locations with varying building heights and locations between buildings, from street center to sidewalk, in order to characterize the urban neutron background and its variability. Future research will also be conducted in several other cities such as Philadelphia and New York.

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