DEVELOPING A SYSTEMS OPTIMIZATION TOOL FOR MONITORING SPECIAL NUCLEAR MATERIAL

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ABSTRACT

Under its international safeguards obligations, a nuclear facility will implement a security system that is developed and designed to incorporate (and hopefully integrate) elements of physical protection and containment and surveillance. Simple nuclear security components can range from closed-circuit camera systems, electromagnetic door locks, motion sensors, physical barriers, portal monitors and other radiation sensors, and radio-frequency identification tags. Integrating these various components into an effective system is difficult yet essential in providing confidence in the security and control of the special nuclear material within the facility. A tool for optimizing various material control and containment and surveillance systems would facilitate effective implementation of these systems for high assurance that material diversion could occur. At Texas A&M University, staff at the Nuclear Security Science and Policy Institute (NSSPI) has begun investigating such a systems optimization tool for various material control and containment/surveillance systems that is to be implemented in a small static, storage facility: an applied safeguards teaching laboratory for graduate-level nuclear engineering students. The facility simulates a typical static professional research laboratory with special nuclear material. The tool is based on using a stochastic radiation transport code for determining vulnerabilities of the installed radiation monitoring systems within the laboratory. In early 2010, NSSPI staff completed a proof of concept by simulating the movement of one highly-enriched uranium source though and out a single room with a single point of exit. The results were indicative of suspected vulnerabilities by the investigators and a more complex design and scenario was then devised for the next scenario: increased radiation attenuation, elevated radiation backgrounds, accelerated motion, more points of access, etc. This presentation will discuss the results of this advanced modeling endeavor and present the work into a hypothetical systems optimization tool that could eventually benefit the nuclear safeguards and security industry.

KEYWORDS: Nuclear Material Monitoring; Systems Optimization

1. Introduction

The Nuclear Security Science and Policy Institute (NSSPI) at Texas A&M University (TAMU) currently operates an applied safeguards technologies laboratory where various material control and accounting (MC&A), physical protection (PP), and containment and surveillance (C/S) systems are used for educational and research purposes for graduate students receiving nuclear engineering degrees yet specializing in nuclear nonproliferation, safeguards, and security. This laboratory is to be used for educating students in various technologies needed to effectively apply nuclear security and safeguards measures via practical exercises using all the equipment and special nuclear material (SNM) housed in the lab space. A basic C/S system has been put in place to secure a small number of SNM sources within the lab and a basic vulnerability assessment of the system has been conducted. The information from a vulnerability assessment is used to optimize the C/S system for maximized material diversion interdiction. The theory behind this system optimization will eventually be translated to other technologies and systems within the laboratory.

2. Vulnerability Assessment on the TAMU ASTL

In the nuclear security industry, vulnerability assessments are used mainly to detect and identify weaknesses in a physical protection system. The challenge at TAMU was to apply this logic to a C/S radiation measurement system within the Applied Safeguards Technologies Laboratory (ASTL). Apart from the primary objective of identifying and evaluating these weaknesses, a secondary result of a vulnerability assessment includes optimization to mitigate the system's vulnerabilities. This step is discussed within the results section of this paper.

As aforementioned, the ASTL houses portal radiation monitors, SNM standards, four gamma monitoring systems, cameras, remotely-controlled MC&A devices, and physical protection instruments such as balanced magnetic switches and other access restricting devices. The primary intent is to use this lab mainly as a teaching laboratory for holding semester-long courses on applied advanced safeguards and security technologies for graduate-level students within the nuclear engineering department at TAMU. Additionally, the laboratory is available for students in need of using the SNM or equipment for their graduate research projects in safeguards or security.

3. Simulation

The laboratory was modeled in three dimensions using a stochastic radiation transport code called Monte Carlo N- Particle (MCNP) developed by staff scientists at Los Alamos National Laboratory[1]. The (MCNP) code allows for structural and radiation modeling and simulation is used to determine the effectiveness of the radiation detection system in place within the TAMU ASTL. For simplicity concerns, the laboratory was modeled as a 9.23-meter (30 feet) by 7.385-meter (24 feet) concrete room with 3.69-meter (12-foot) high concrete ceilings. There is a single point of entry and no other external access points (i.e., windows or gates). The furniture fixtures were kept at a minimum including a wooden work bench along a freestanding concrete wall outlining the entrance/exit ramp into the lab and the steel safe where the sources are housed. Figure 1 shows a bird's-eye view of the laboratory with approximate dimensions (not to scale).

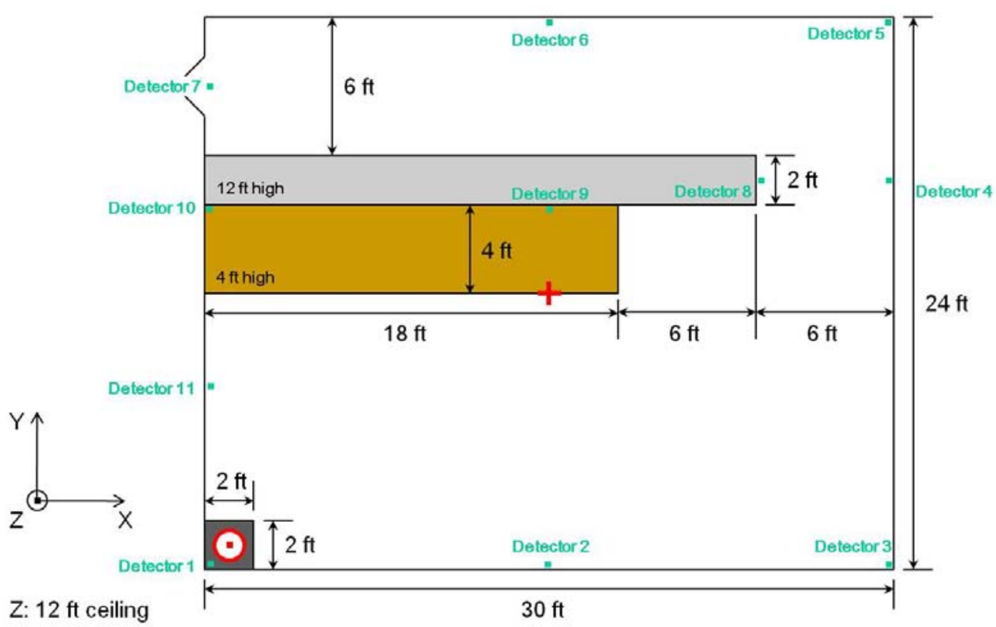

Figure 1. TAMU ASTL with source in safe (the red/white target is the source)

The radiation detection system consists of Canberra G64 Monitors (Geiger-Muller (GM) tube-based detectors) used for gross photon counts and intends to detect any movement of a given radioactive source via the placement of the detectors. A total of eleven point detectors were simulated in the model in order to choose an optimal subset/location of detectors for the given laboratory space. Enriched ^{235}U- radiation source model based on the 4.46%-enriched uranium standard from the NBL

CRM 969 set was considered for the simulation placed at various locations along a suspected adversarial pathway within the lab. The results are given per single photon emitted per second and furthermore, the detector tallies are assumed as flux tallies in units of photons/cm^2-s. The adversarial pathway begins from the source kept in the storage safe and twenty source location points outside the safe as the source nears the point of exit. Figure 1 shows the starting point of the simulation (the source is the red/white target within the steel source storage safe in the lower left-hand corner). Figure 2 displays the pathway (21 source positions outside of the safe) with the eleven hypothetical detectors.

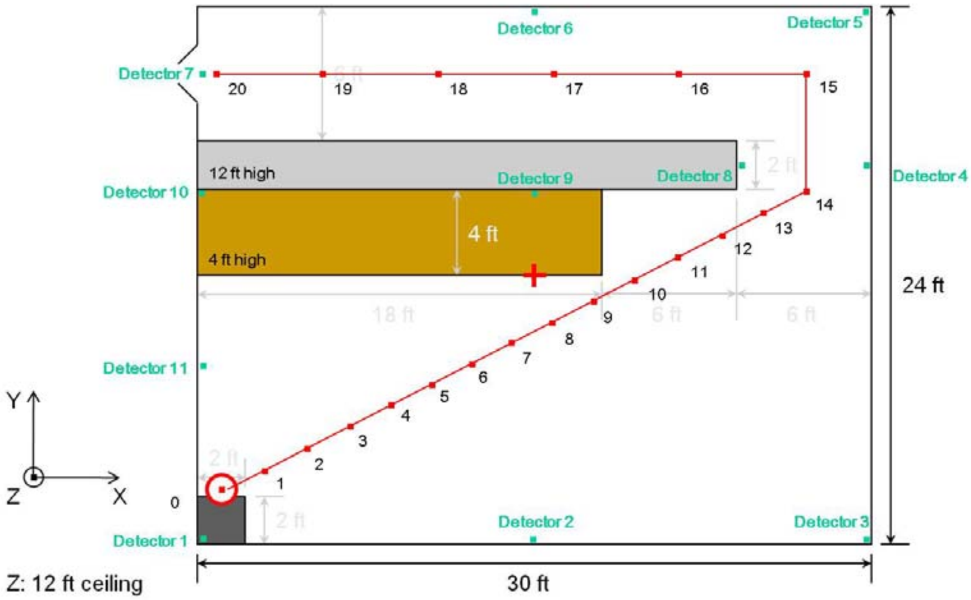

Figure 2. TAMU ASTL with defined source pathway (source is outside safe)

Initially, the defined pathway used is simple straight-line pathway to the point of exit. For this activity, it was assumed that the simplest case would be evaluated for determining the feasibility of the theory and further scenarios would eventually be implemented if the initial case provided adequate results. With this path, from the eleven detectors flux results were tallied and then a subset from it was chosen to optimize the detector system.

4. Results

The simulation results shown in figure 3 are in units of photons/cm^2-sec per source strength of one photon per second. There are twenty-one positions. Conceptually, the data supports the theory of tracking material movement via the detector system. With a given threshold of 1E-6 photons/cm^2-sec per one photon per second, figure 3 conveys that an aggregate of detector locations 11, 9, 4, and 6 will create the closest semblance of continuous material tracking using the minimal number of detectors from initially removing the source from the safe to removing the source entirely from the room.

Figure 4 shows the resulting detector profiles when the superfluous detectors are removed. It is important to note that at source location 20, the reading from Detector 6 drops below the aforementioned threshold (circled in red). Ideally, it would benefit the facility to utilize Detector 7's location but within the limitation of resources posed by the exercise, it is beneficial to show the efficacy of optimizing the placement of Detector 6 to meet the needs of the system.

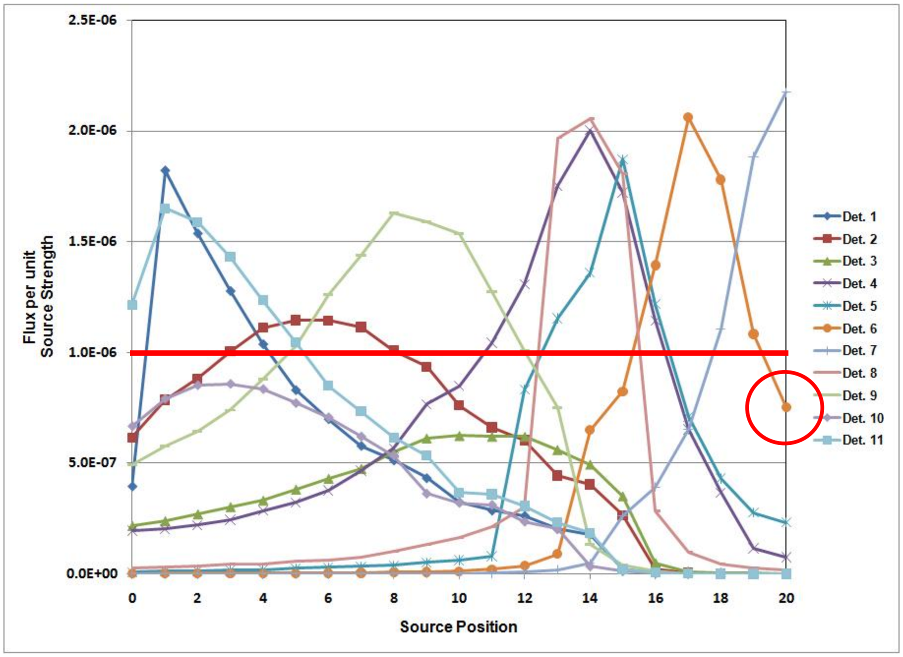

Figure 3. Flux per unit Source Strength vs Source Position for 11 detectors

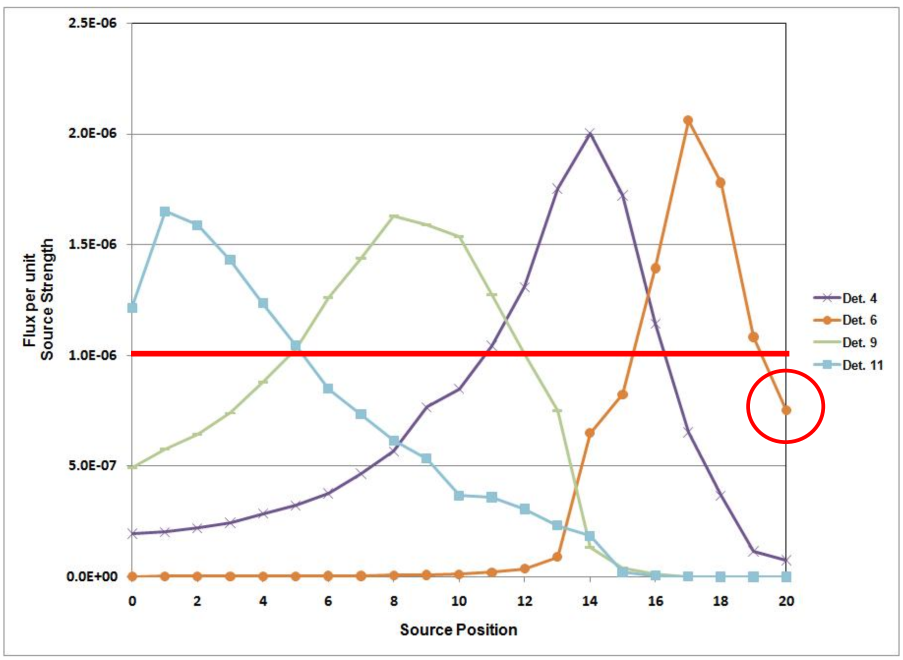

Figure 4. Flux per unit Source Strength vs Source Position for Detectors 4, 6, 9, and 11

Within the confines of only using four detectors, Detector 6 was repositioned to an optimized location (80 centimeters in the –X direction) that will mitigate the low count rates exhibited by source location 20. Figure 5 shows the repositioning of Detector 6 and figure 6 shows the effect of this on the profile of the source tracking.

Overall, the results convey that the exercise was a success and that material, albeit in a rudimentary setting, can be tracked through a given, simple facility based on these simulations.

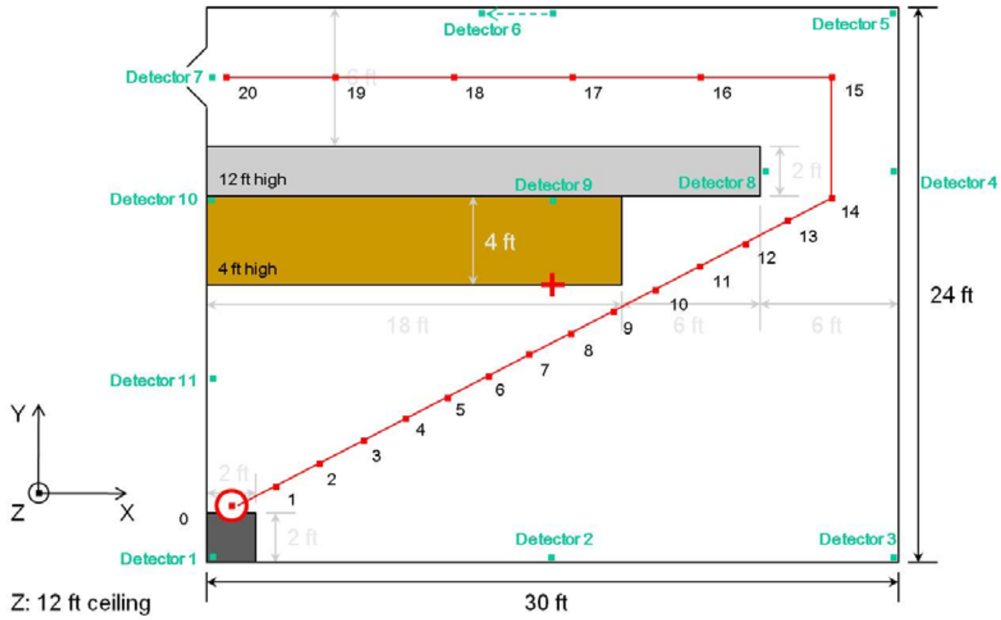

Figure 5. Detector 6 repositioned for 4-detector optimized system

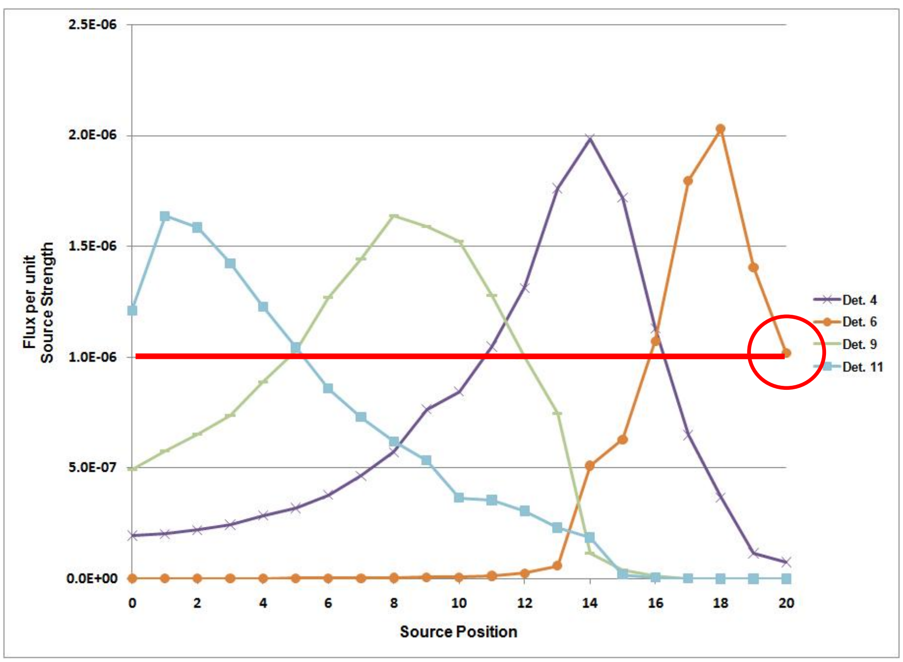

Figure 6. Flux per unit Source Strength vs Source Position for Detectors 4, 6 (modified), 9, and 11

5. Future Work

The investigators made assumptions in the simulated exercise to simplify the intricacies of the ASTL at TAMU and the sources that are to be used eventually in a system such as this. In future incarnations of the system, more detailed detectors, sources, and facility space will be incorporated to better fit the needs of the system. In light of the simplification measures taken by the team, it is believed that the resulting data convey favorable results for optimizing a material tracking system using a stochastic method/code such as MCNP5. Ultimately, as this project evolves, added considerations will be made to factor sensitivities of the detector configurations and details of the radioactive sources. Further, it is envisioned that the research team will utilize knowledge gleaned from this exercise more accurately model the laboratory space and determine the system's vulnerabilities. Important among the considerations when continuing with this work in the future include modifying the detector tally points in MCNP to fully modeled scintillator detectors; characterizing the performance of the system with considerable amounts of background radiation (apply realistic scenarios instead of a low-background experimental situation); and including other, less detectable, sources beyond the 1.001 MeV photon typical of ^{238}U. As previously mentioned, the researchers will also use experience taken from this exercise and apply it to other relevant technology as applied in nuclear material tracking in a given static facility monitoring such as optical surveillance. It is believed that lessons learned from the basic stochastic modeling methods used in a Monte Carlo code, can be applied to other fields and this exercise is a clear first step in that direction.

6. Conclusions

In conclusion, the results of this exercise exhibit that a stochastic, Monte Carlo code (such as MCNP) can be used as a valuable system optimization tool for a basic C/S or material tracking system using radiation monitors in a static facility. Lessons from this work can be used in safeguarding any nuclear facility where optimization of a limited number of radiation detectors is essential. This limitation is a real-world situation that almost all facilities face continuously in today's world. Whereas the initial reaction for enhancing an existing system would be to merely add detectors, this exercise determined that detector placement is just as important to the adequate and effective operation of a radiation C/S system in a given facility. Furthermore, an optimized radiation detection system can be supported by a secondary system (e.g., optical) that would benefit greatly from the applied data gleaned from this exercise. Overall, this exercise showed the feasibility of optimizing a material tracking system by optimizing a system of detectors using the radiation transport code MCNP. In TAMU's nuclear engineering MS degree program in Nonproliferation, this activity has been incorporated into an advanced safeguards course to educate graduate students on the value of optimizing a system using a code with which they are highly familiar.

7. Acknowledgements

The research team would like to extend gratitude to Dr. William S. Charlton of Texas A&M University and the Nuclear Security Science and Policy Institute for providing the means and resources in conducting this work as well as provided the initial idea for this exercise.

8. Legal Matters

8.1. Privacy regulations and protection of personal data

8.2. Copyright

9. References

1. X-5 Monte Carlo Team, 2005 MCNP-A general purpose Monte Carlo N-Particle Transport Code, Version 5, LANL Report No. LA-UR-03-1987.