Genetic Algorithm Optimization of Tin-Copper Graded Shielding for Improved Plutonium Safeguards Measurements

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Introduction and Motivation

- **MISSION RELEVANCE:** International nuclear safeguards are used to control special nuclear material such as plutonium, and are quintessential to global security and safety
- Recently, more interest has been shown in organic scintillation detectors for safeguards measurements as opposed to the current state-of-the-art $^{3}\mathrm{He}$ detectors
- Organic scintillation detectors do not need to moderate neutrons to improve detection efficiency and are also sensitive to photons
- Current Limitation: data throughput and pulse pile-up because of $^{241}\mathrm{Am}$ buildup in plutonium samples, which emits 60 keV gamma rays with high specific activity
- **WANT:** higher energy fission gamma rays and neutrons
- **DON'T WANT**: lower energy non-fission gamma rays, predominantly from $^{241}\mathrm{Am}$
- **SOLUTION:** use genetic algorithm to design a tin-copper graded shield that preferentially shields low energy gamma rays, while minimizing intensity loss of fission signatures

Complete Solution Space Search Method	Genetic Algorithm
Solution Space: 1 cm X 1 cm	Population: 36
Shield Thickness Discrimination: 0.0001 cm	Generations: 50
Time per Simulation: 3 minutes	Time per Simulation: 3 minutes
MCNPX-PoliMi Simulations: 10^8	MCNPX-PoliMi Simulations: 1.8×10^3
Total Time: 571 years	**Total Time: 4 days**

Figure 1: The two blocks show the total time saved by implementing a genetic algorithm.

Simulation Setup

- Simulations will be used to determine optimal dimensions for tin-copper graded shield
- 2 Simulation Templates: (1) beam source of 60 keV gamma rays from $^{241}\mathrm{Am}$ and (2) beam source of spontaneous fission photons from $^{240}\mathrm{Pu}$

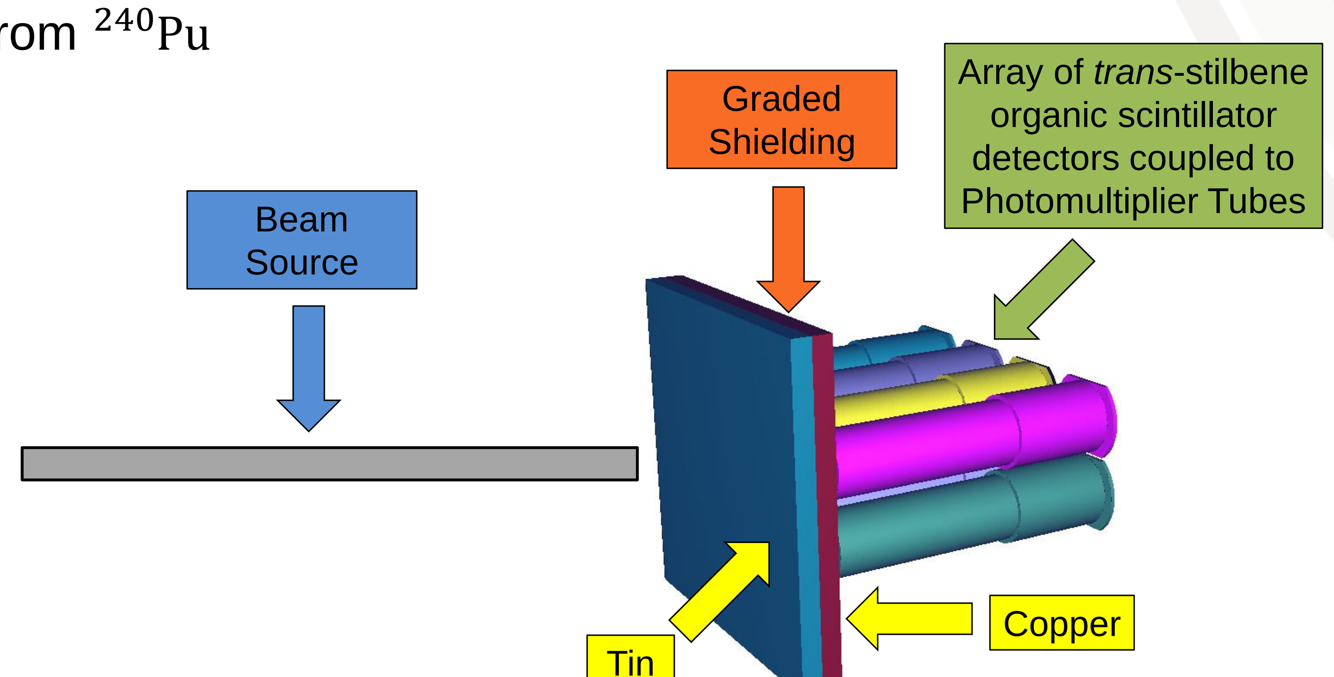

Figure 2: A 3-D side view of the simulation geometry.

Genetic Algorithm Methods

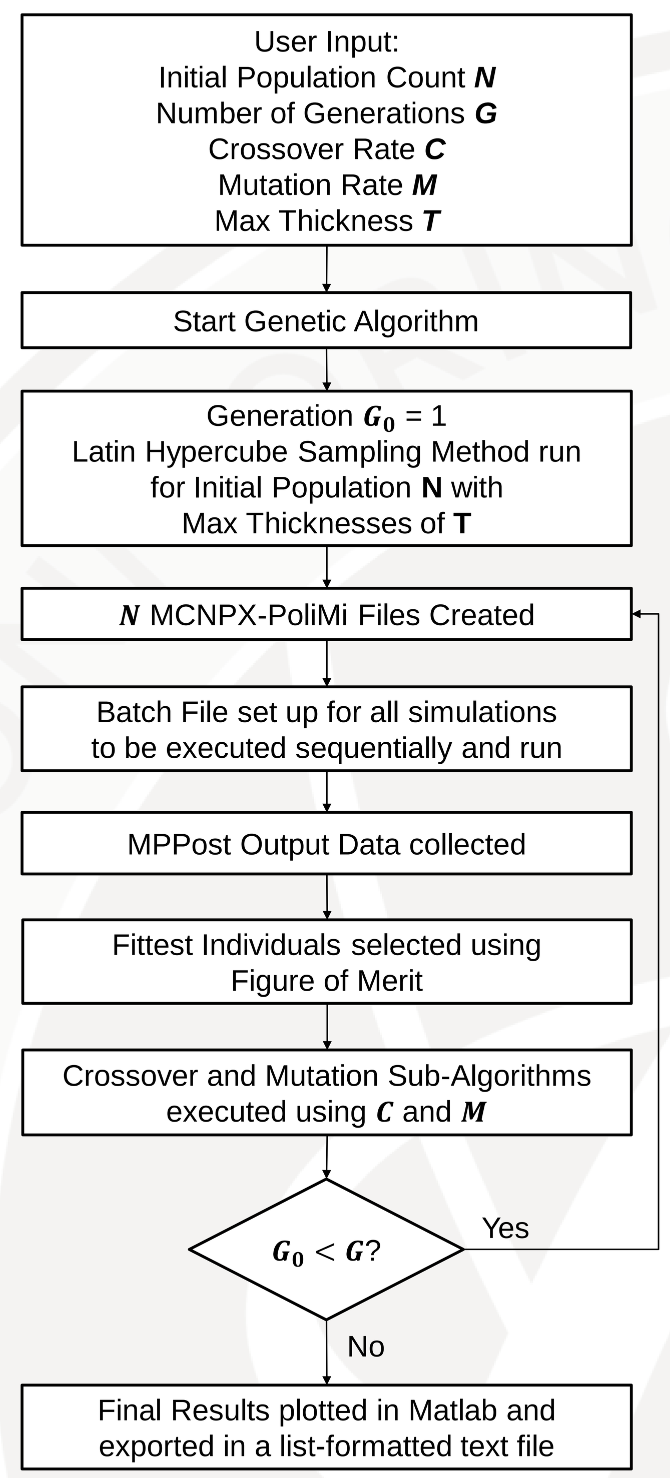

Figure 3: A schematic of the genetic algorithm's internal operations.

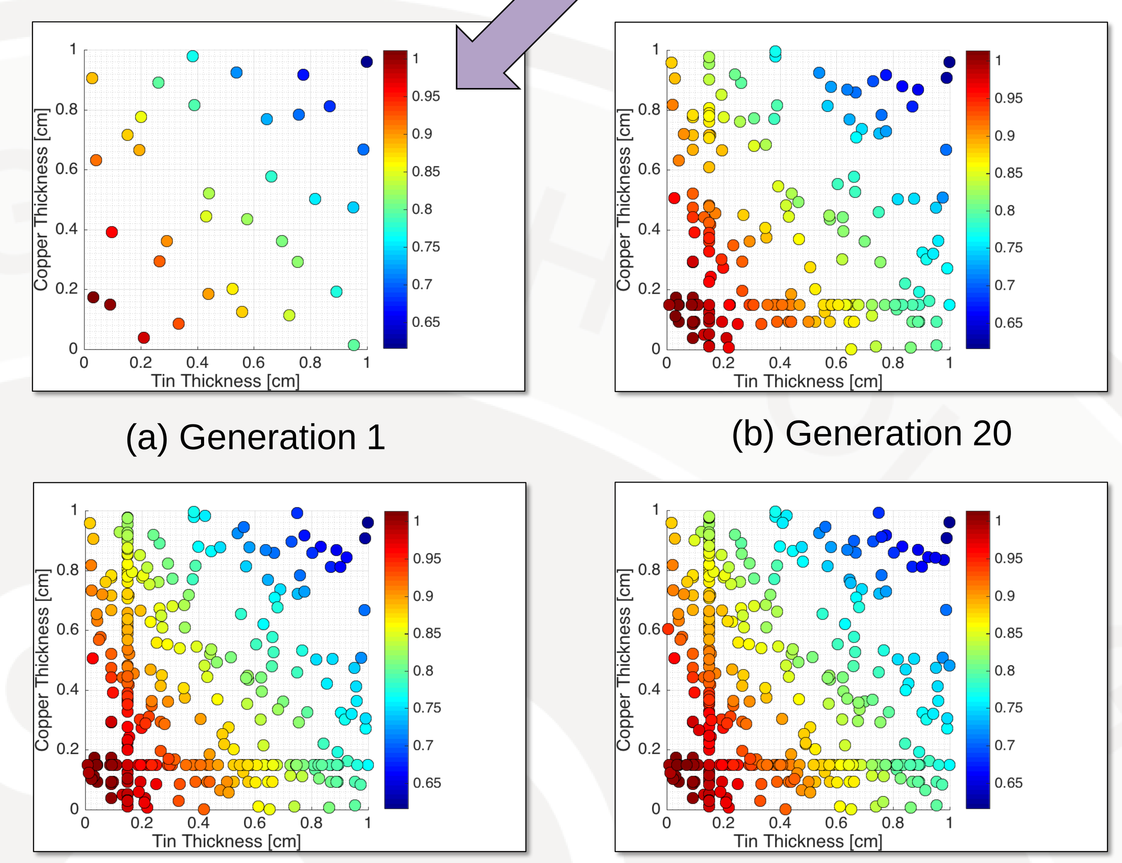

Figure 4: Evolution of shielding designs with $^{241}\mathrm{Am}$ attenuation weighting factor C of 0.01.

Color Bar refers to Figure of Merit (FoM)

$$\mathrm{FoM} = \frac{r_{240}}{r_{241} + C}$$

$$r_{240} = \frac{\mathrm{n}_{240}}{\mathrm{NPS}_{240}} \qquad r_{241} = \frac{\mathrm{n}_{241}}{\mathrm{NPS}_{241}}$$

n_{240} = number of $^{240}\mathrm{Pu}$ gamma-ray detections
n_{241} = number of $^{241}\mathrm{Am}$ gamma-ray detections
NPS_{240} = number of particles simulated for $^{240}\mathrm{Pu}$
NPS_{241} = number of particles simulated for $^{241}\mathrm{Am}$
C = $^{241}\mathrm{Am}$ attenuation weighting factor

Genetic Algorithm Results

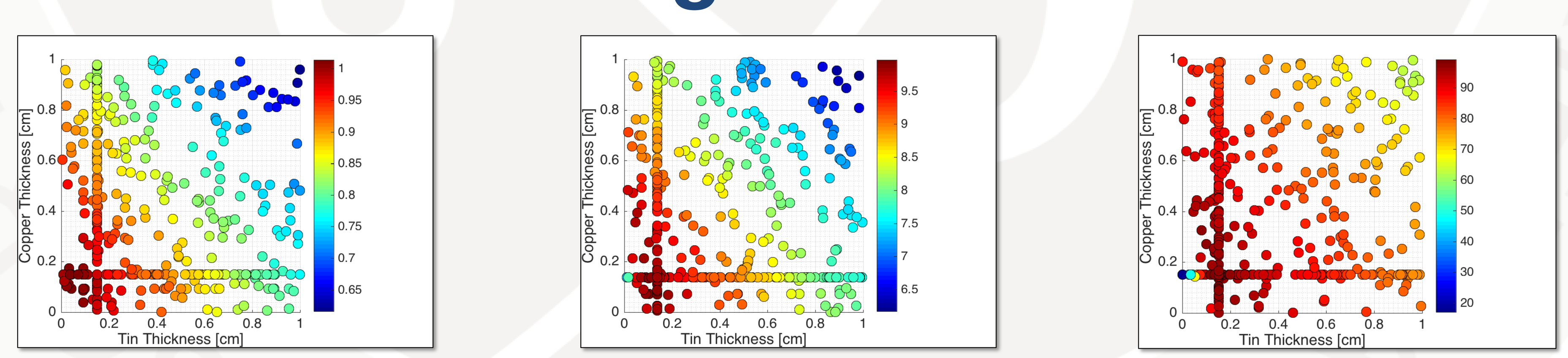

Figure 5: Generation 50 of shielding designs with $^{241}\mathrm{Am}$ attenuation weighting factor C of 0.01 (left), 0.001 (middle), and 0.0001 (right).

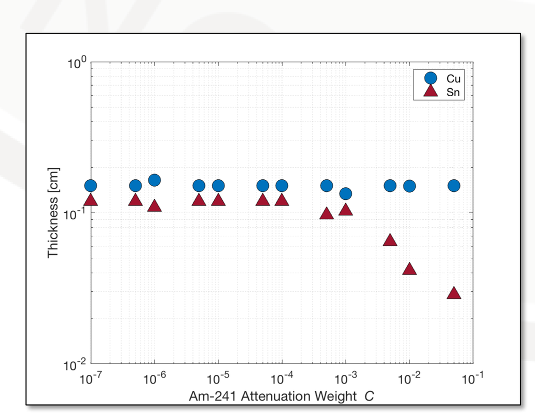

Figure 6: Thickness of shielding material plotted as a function of the $^{241}\mathrm{Am}$ attenuation weighting factor C.

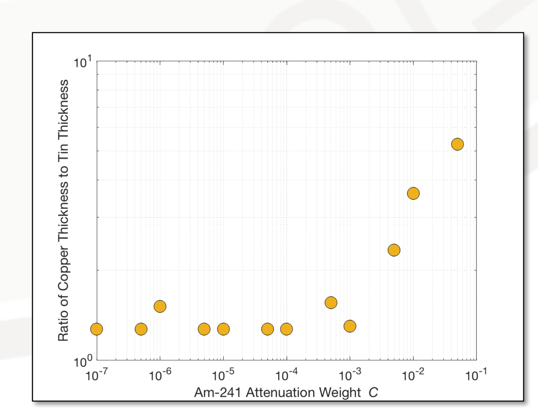

Figure 7: Ratio of copper to tin plotted as a function of the $^{241}\mathrm{Am}$ attenuation weighting factor C.

Experimental Setup

- Shielding was placed in front of 12 cylindrical, 5.08 cm by 5.08 cm diameter *trans*-stilbene organic scintillation detectors for a measurement of approximately 4.5 kg of alpha-phase, weapons-grade plutonium, an AmLi source, and a $^{252}\mathrm{Cf}$ source

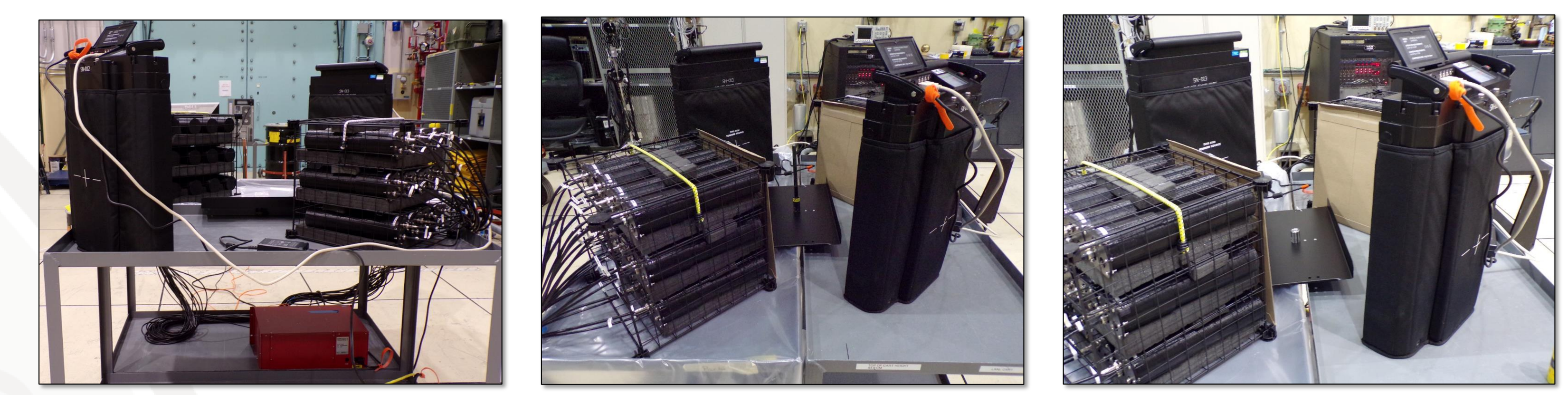

Figure 8: Experimental setup with no source and no shielding (left), $^{252}\mathrm{Cf}$ source and shielding (middle), and AmLi source and shielding (right).

Experimental Results

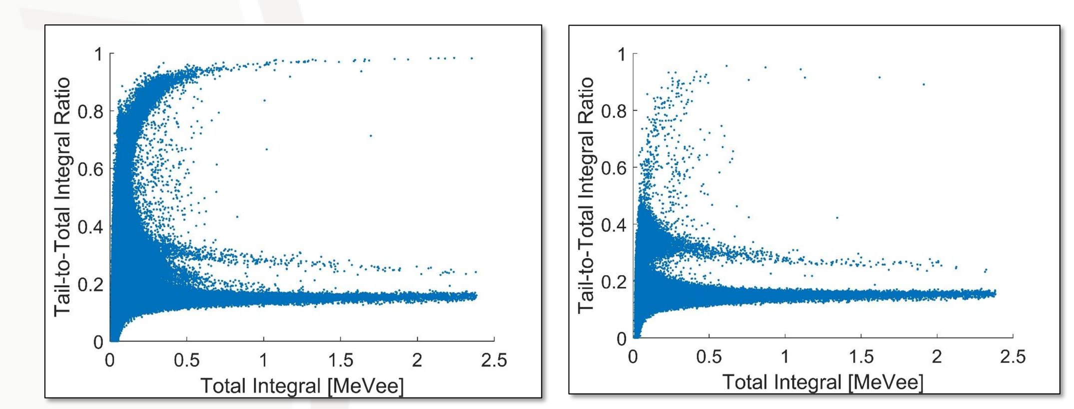

Figure 9: Pulse shape discrimination of AmLi source measurement without shielding (left) and with shielding (right).

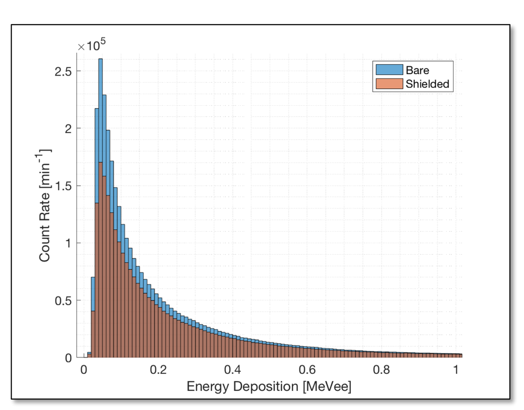

Figure 10: Count rate of $^{252}\mathrm{Cf}$ source plotted as a function of energy deposition with and without shielding.

Conclusions

- Demonstrated efficacy of genetic algorithm in nuclear engineering application
- Resultant reduced gamma-ray flux will allow detection systems to be placed closer to plutonium sources in the future, therein increasing detection efficiency
- Improved efficiency offers many advantages including better measurement precision and shorter required measurement times
- **FUTURE WORK:** Quantify uncertainty of genetic algorithm and test genetic algorithm with other shielding applications

MTV Impact

- MTV has enabled me to conduct research and attend/present at the Engineering Research Symposium, where I won the Engineering Innovation Award
- I will be traveling to Los Alamos National Laboratory this summer for an internship obtained with connections from MTV

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