MTV Student Virtual Research Symposium

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

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Noah Kleedtke
University of Michigan
Department of Nuclear Engineering and Radiological Sciences
PI: Sara Pozzi, Mentor: Michael Hua

Introduction and Motivation

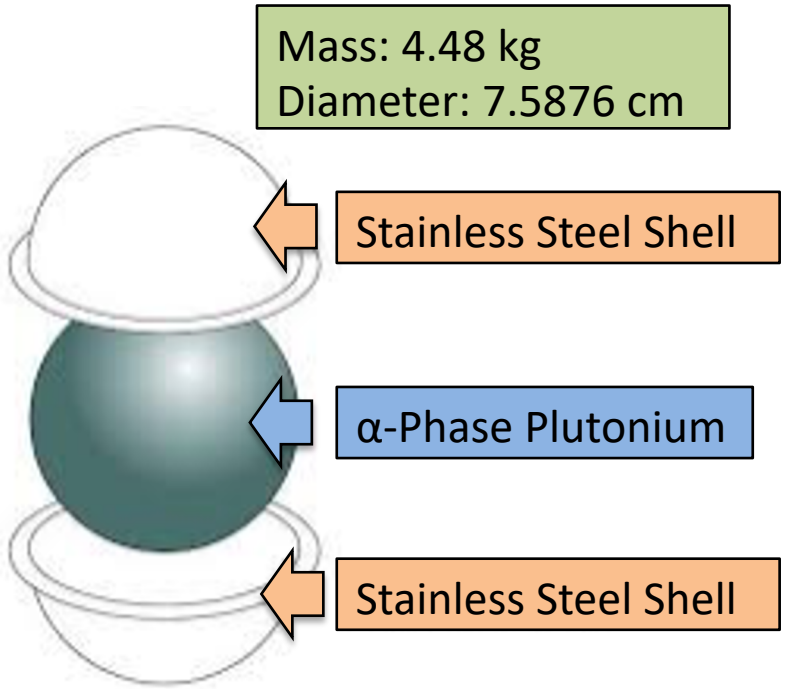
- Atoms for Peace (1953)
- Non-proliferation Treaty (NPT) (1968)
  - Each nuclear-weapon State Party agrees not to transfer any nuclear weapons to a non-nuclear-weapon State Party
  - Each State Party agrees to accept international safeguards set up by the IAEA
- Nuclear Safeguards
  - Validation and Verification
  - Special Nuclear Material (SNM)
- Organic Scintillation Detectors
  - Fast timing capabilities
  - Sensitive to both neutrons and photons

ABOVE: President Eisenhower giving his "Atoms for Peace" proposal to United Nations General Assembly (Photo: United Nations)

ABOVE: IAEA inspectors in nuclear power plant, **RIGHT:** IAEA inspector measuring LEU (Photos: IAEA)

Introduction and Motivation

- Device Assembly Facility, Nevada National Security Site (NNSS)
- **Be**ryllium-**R**eflected, alpha-phase, weapons-grade **P**lutonium (**BeRP** ball)
- **LIMITATION:** data throughput and pulse pile-up because of Am-241 buildup in plutonium samples
- Am-241 emits 60-keV gamma rays with a high specific activity of 3.428 Ci/g
- **WANT:** higher energy fission gamma rays and neutrons
- **DON'T WANT:** lower energy non-fission gamma rays, predominantly from Am-241



BeRP ball (Photo: Hutchinson et al.)

Isotope	Approximate Weight Percent
Pu-238	0.02
Pu-239	93.74
Pu-240	5.94
Pu-241	0.269
Pu-242	0.028
Am-241	557 ppm

Introduction and Motivation

- **PROPOSED SOLUTION:** use a genetic algorithm to design a tin-copper graded shield that preferentially shields low-energy gamma rays, while minimizing intensity loss of fission signatures
- **GOALS:** (1) shield low-energy gamma rays (particularly those from Am-241) and still detect fission neutrons and photons and (2) demonstrate the efficacy of genetic algorithms in multi-variate (e.g., multi-material) shielding optimization

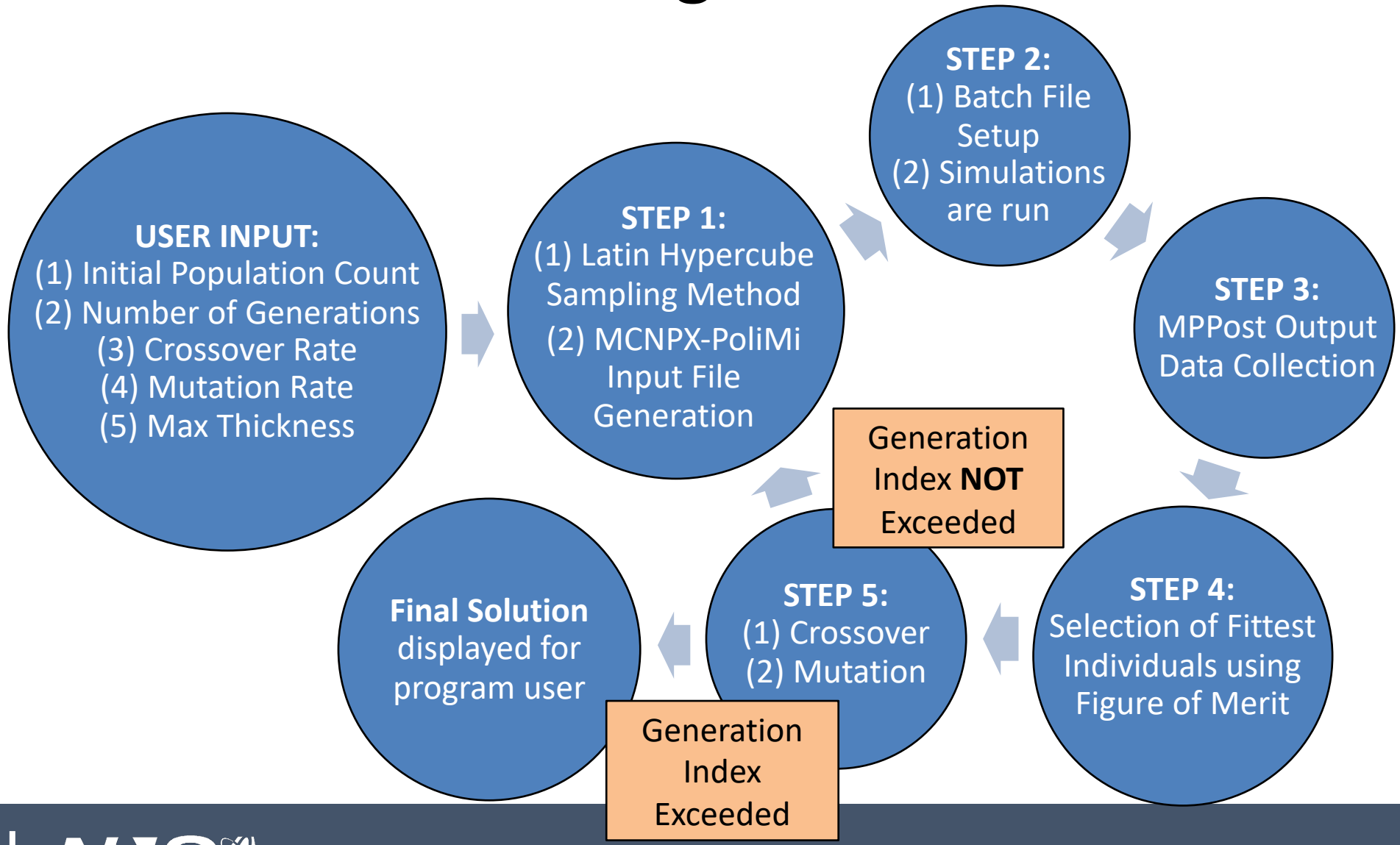
Complete Solution Space Search Method
Solution Space: 1 cm X 1 cm
Shield Thickness Discrimination: 0.0001 cm
Time per Simulation: 3 minutes
MCNPX-PoliMi Simulations: 10^8

Total Time: 571 years

Genetic Algorithm
Population: 36
Generations: 50
Time per Simulation: 3 minutes
MCNPX-PoliMi Simulations: 1.8×10^3

Total Time: 4 days

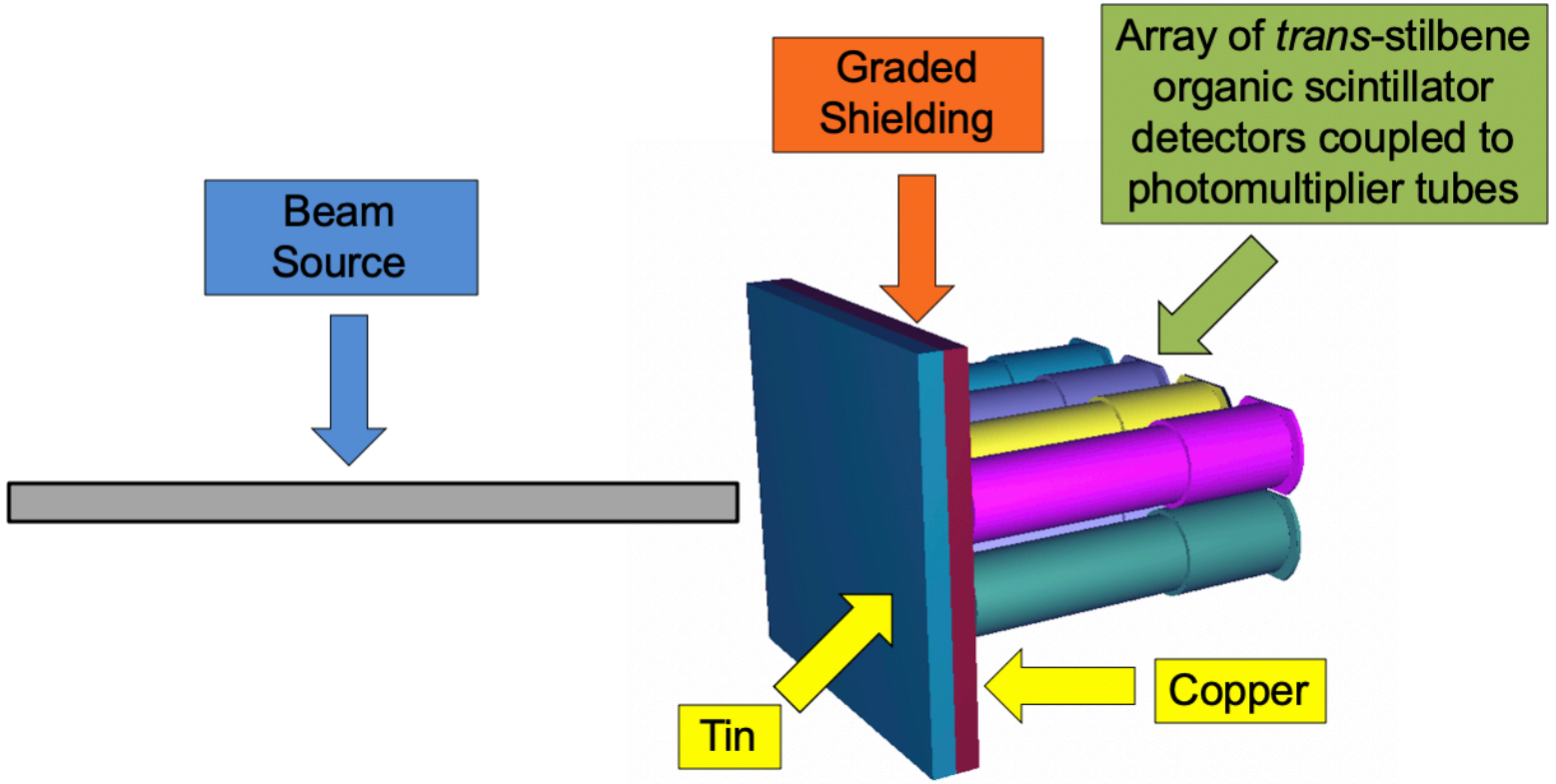
Genetic Algorithm Methods



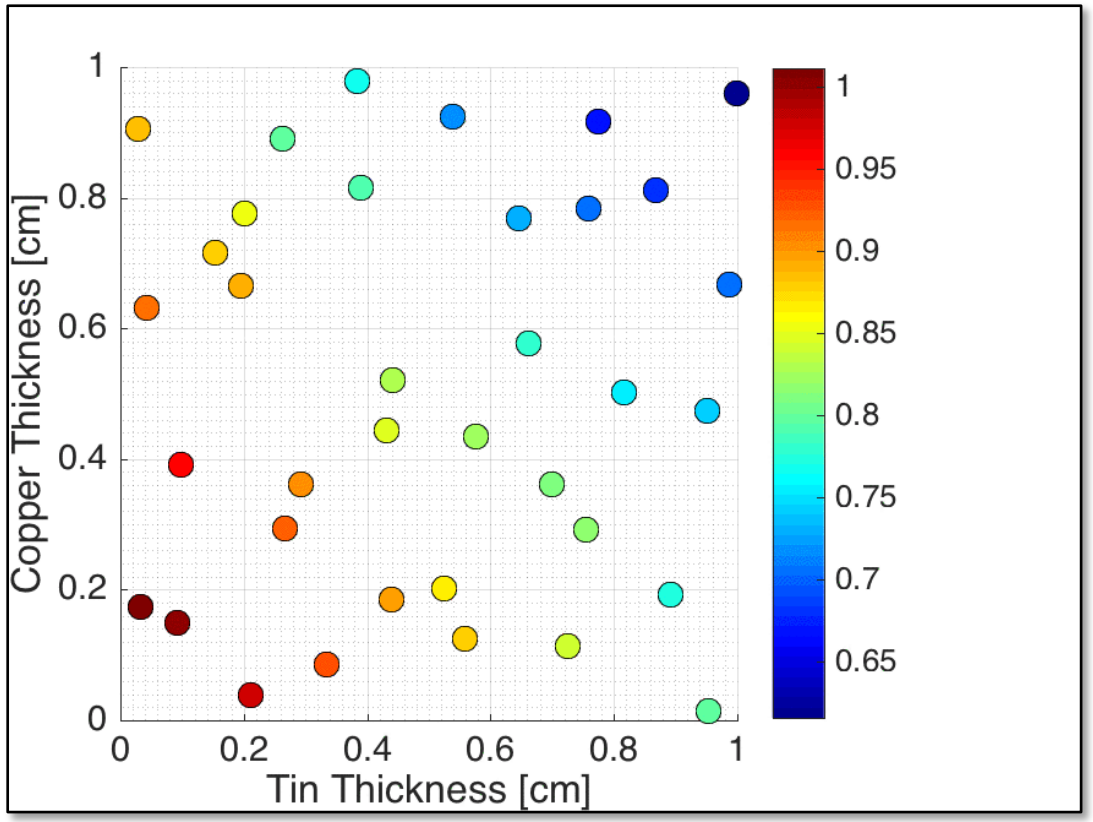
noahklee@umich.edu

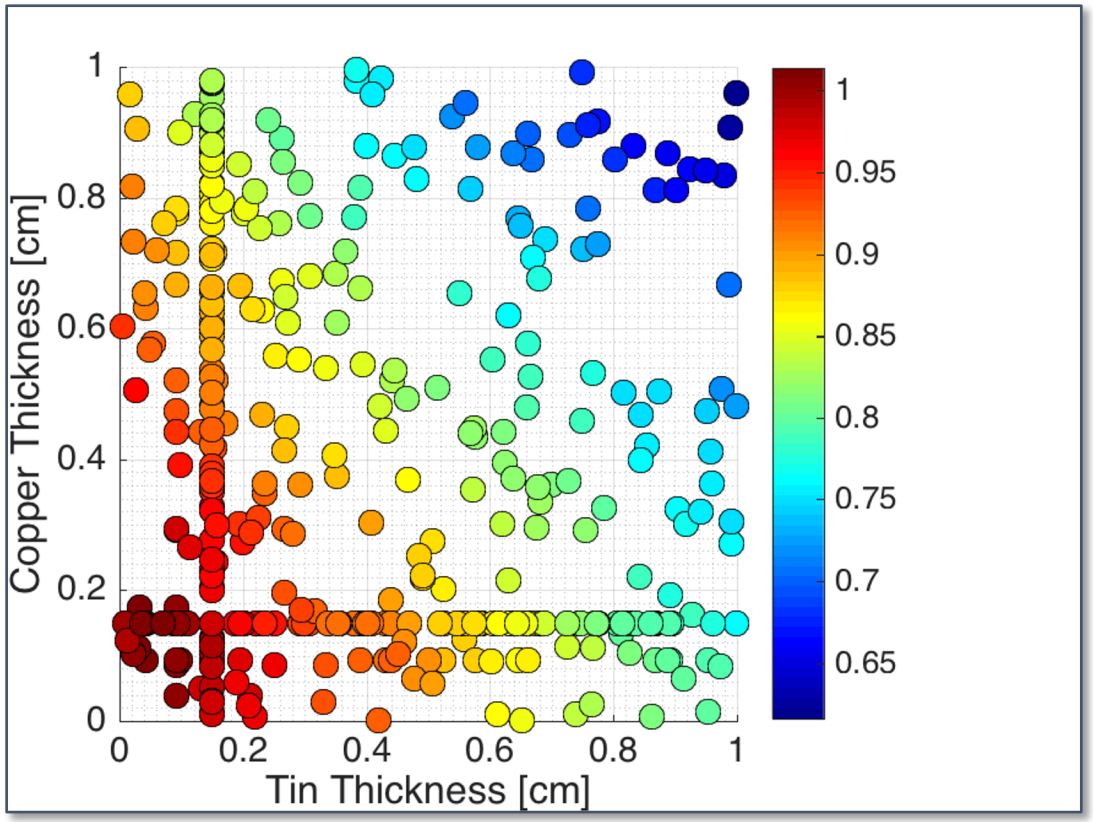
Simulation Setup

- Simulations will be used to determine optimal dimensions for tin-copper graded shield
- 2 Simulation Templates:
  - Beam source of 60-keV gamma rays from Am-241
  - Beam source of spontaneous fission photons from Pu-240



Genetic Algorithm Results



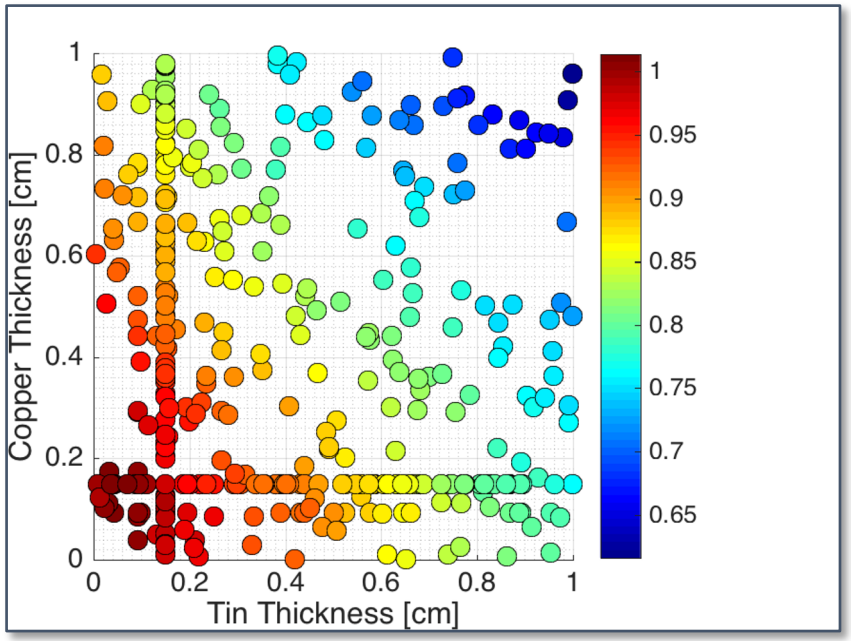


$$\text{FoM} = \frac{r_{240}}{r_{241}+\mathbf{0.01}},\ r_{240} = \frac{n_{\text{Pu-240}}}{\text{NPS}_{\text{Pu-240}}},\ r_{241} = \frac{n_{\text{Am-241}}}{\text{NPS}_{\text{Am-241}}}$$

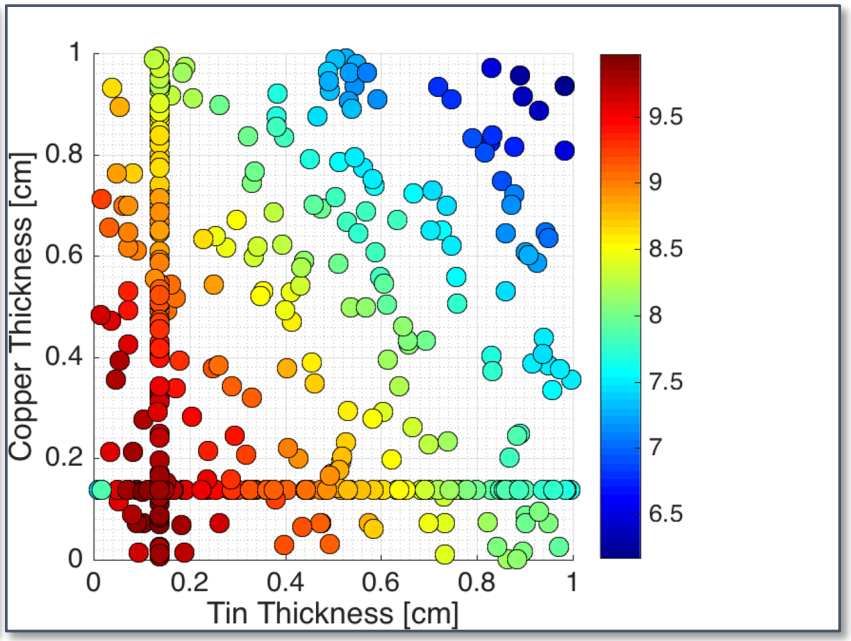
Population Size: 36, Mutation Rate: 16.67% , Generations: 50

Genetic Algorithm Results

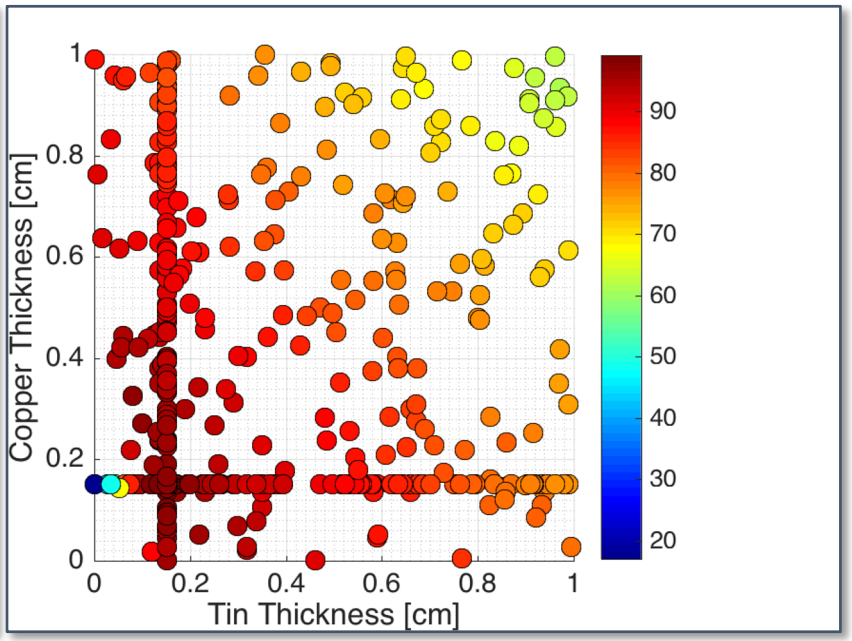
$C = 0.01$



$C = 0.001$



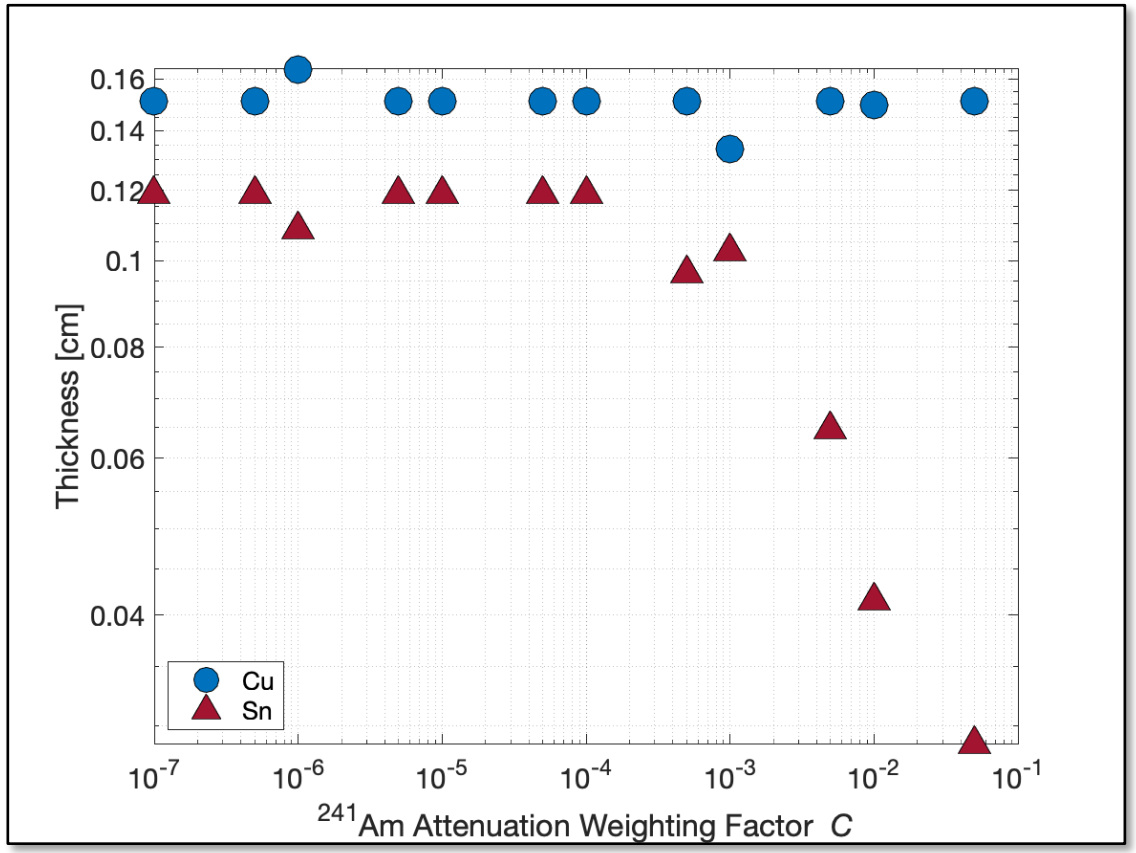
$C = 0.0001$



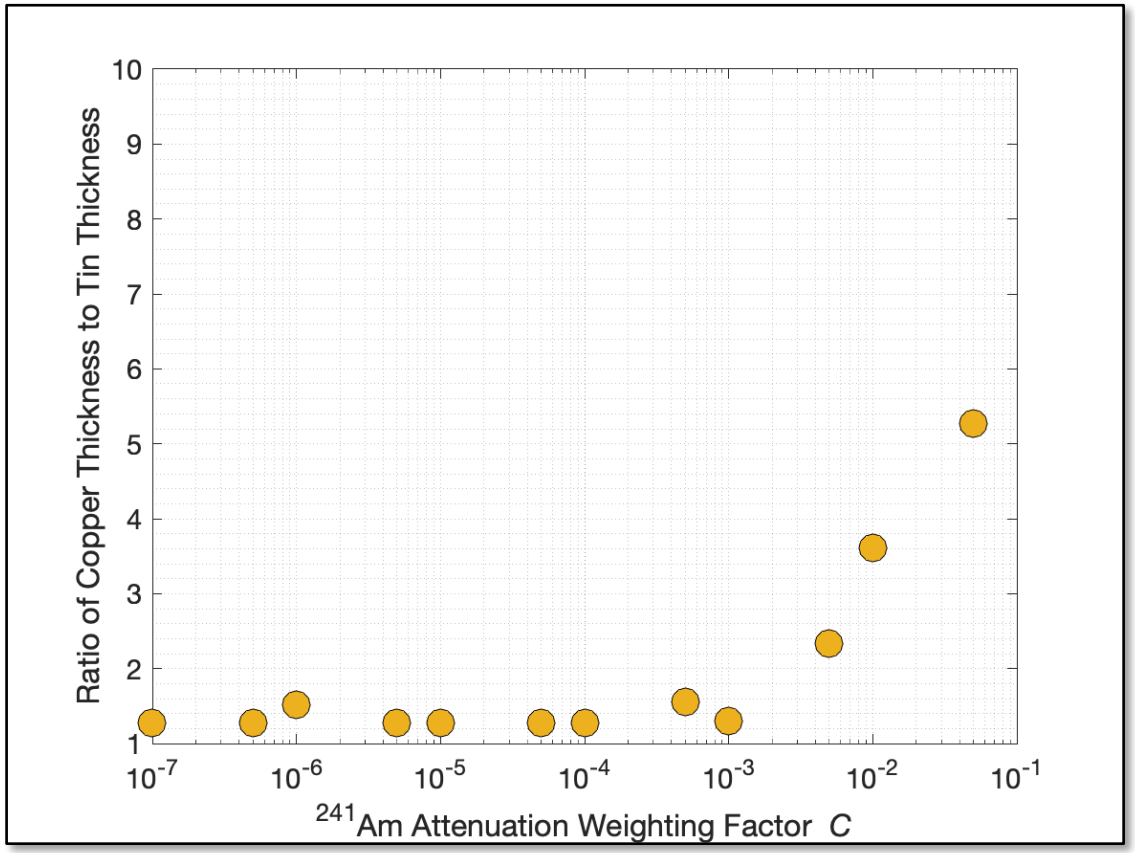
$$\text{FoM} = \frac{r_{240}}{r_{241} + C}, r_{240} = \frac{n_{\text{Pu-240}}}{\text{NPS}_{\text{Pu-240}}}, r_{241} = \frac{n_{\text{Am-241}}}{\text{NPS}_{\text{Am-241}}}$$

Population Size: 36, Mutation Rate: 16.67% , Generations: 50

Genetic Algorithm Results



Thickness of shielding material plotted as a function of the Am-241 attenuation weighting factor *C*



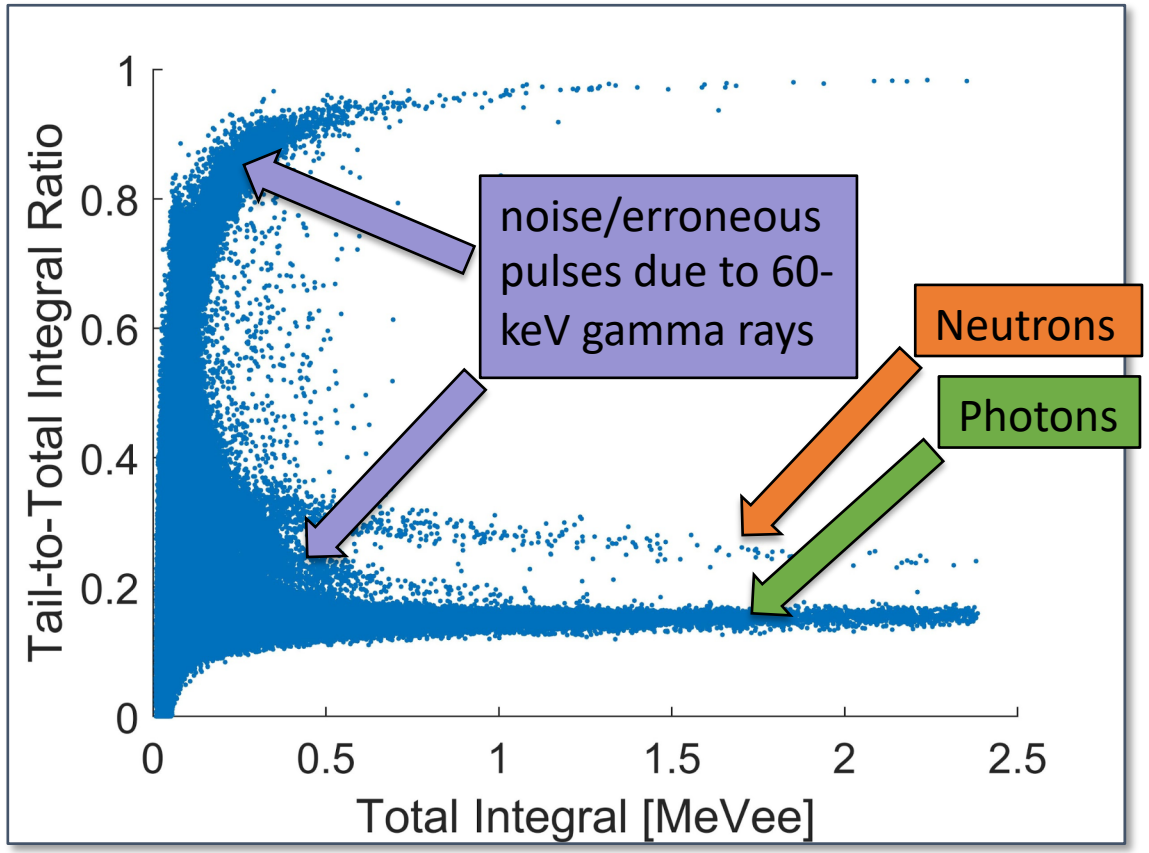
Ratio of copper to tin plotted as a function of the Am-241 attenuation weighting factor *C*

Experimental Setup

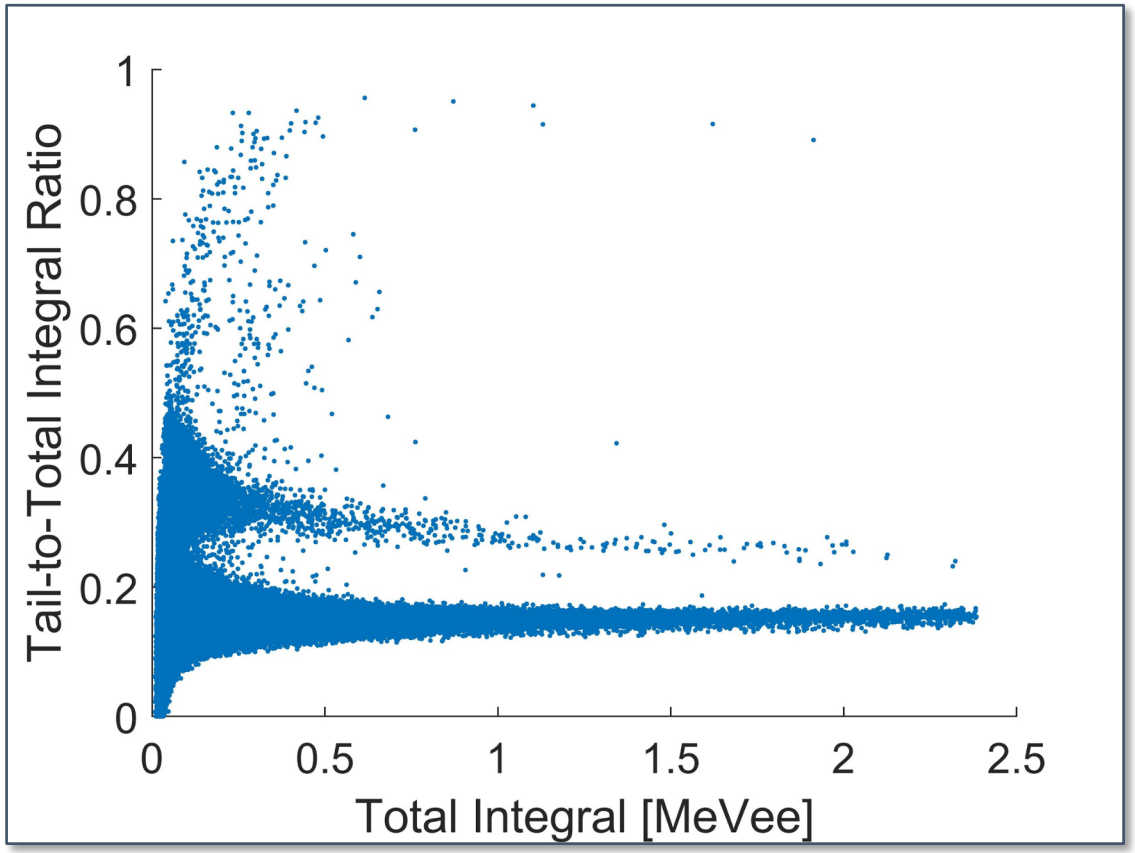
An image of the experimental setup with the **Cf-252 source** and tin-copper graded shields

An image of the experimental setup with the **BeRP ball** and tin-copper graded shields

AmLi Experimental Results

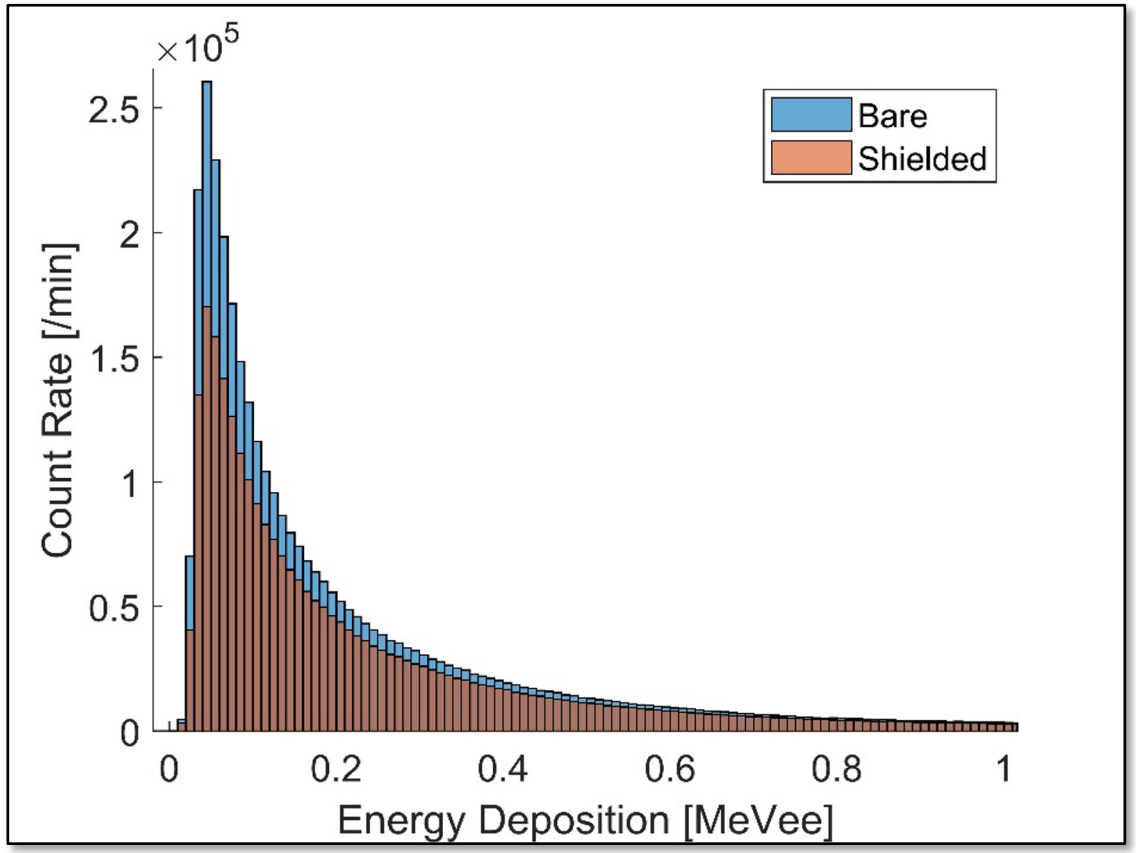


Pulse shape discrimination plot of the AmLi source measurement **WITHOUT** tin-copper graded shields

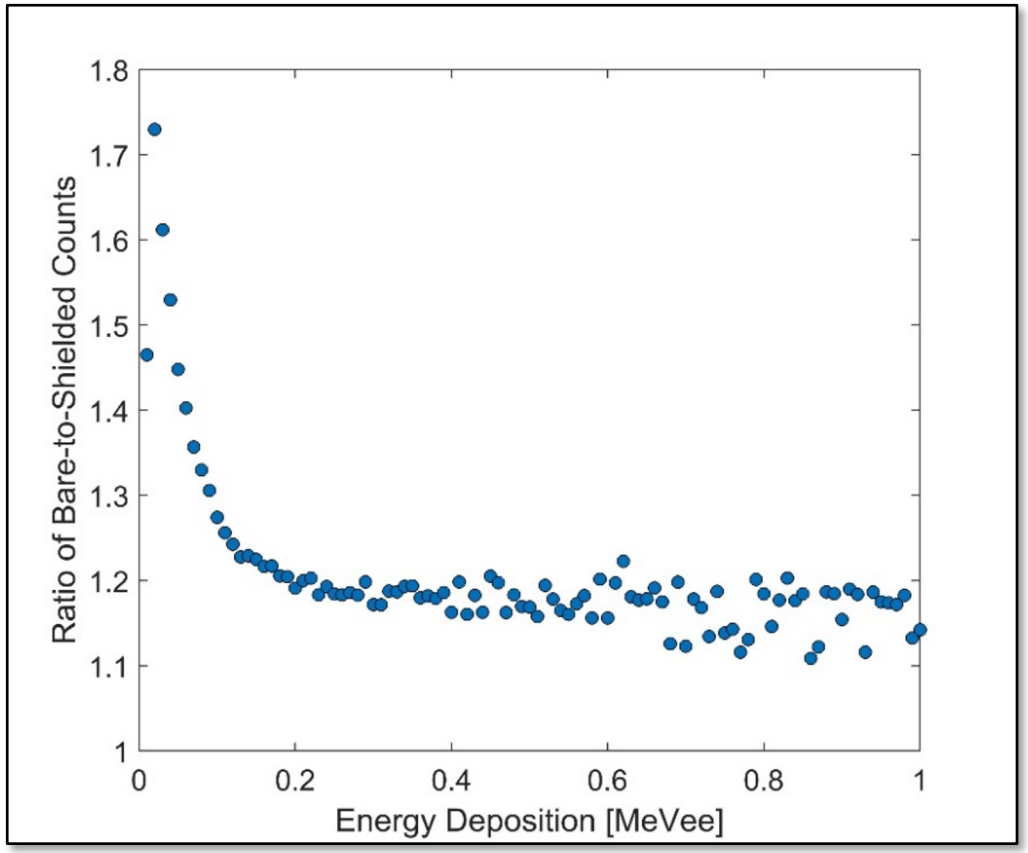


Pulse shape discrimination plot of the AmLi source measurement **WITH** tin-copper graded shields

Cf-252 Experimental Results



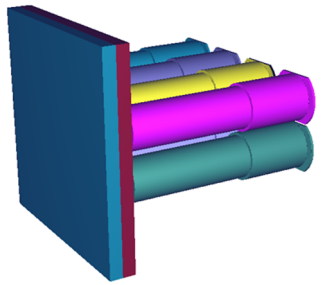
Count rate of Cf-252 source as a function of energy deposition without and with tin-copper graded shields

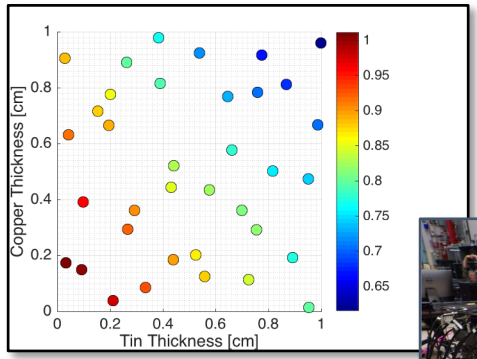


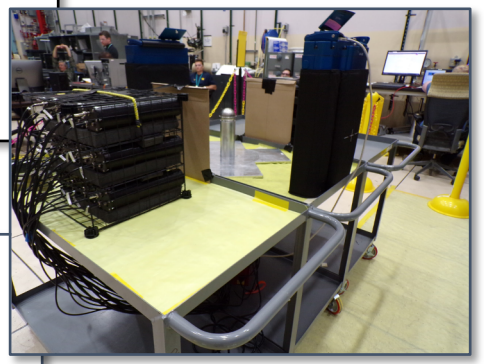
Ratio of bare-to-shielded counts of Cf-252 source plotted as a function of energy deposition

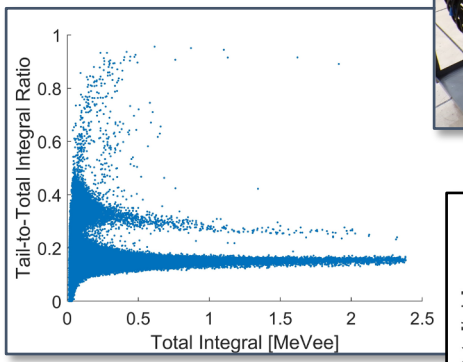
Conclusions

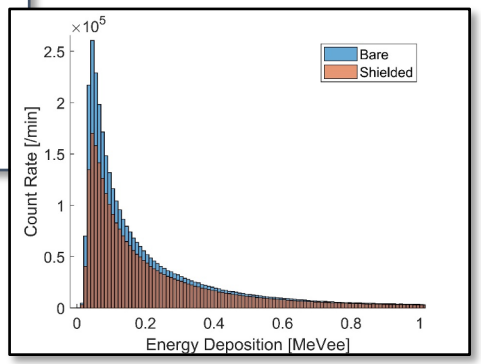
- Demonstrated efficacy of genetic algorithm in nuclear engineering applications
- Resultant reduced gamma-ray flux will allow detection systems to be placed closer to plutonium sources in the future, therein increasing detection efficiency
- Improved efficiency offers many advantages including better measurement precision and shorter required measurement times
- **FUTURE WORK:** Quantify uncertainty of genetic algorithm and test genetic algorithm with other shielding applications
- **MTV IMPACT:** Workshops, Conferences, and Los Alamos National Laboratory (LANL) Summer Internship











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