Optimization of Container Inspection at Port-of-Entry

Effects of Nuclear Shielding on POE Detection

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Introduction: Motivation & Overview

- The rise of globalization has caused a significant increase in the amount of international cargo transported to the U.S. by sea.
- This amplifies the necessity for methods to safeguard ports-of-entry from undesirable shipments (nuclear materials, biological agents, drugs, weapons, etc.).
- The previous work of the POE group detailed a multi-objective optimization approach to determine the optimal sensor threshold level and station sequence, incorporating misclassification and measurement error.

Introduction: Port-of-Entry Problem

- Containers arrive at a port-of-entry for inspection
    - *n* attributes tested independently
- Sensors used to classify attributes of a container as safe (d_i=0) or suspicious (d_i=1) based on selected threshold values T_i for station *i*
- Overall accept/reject decision *D* is based on specified Boolean function of station decisions
    - Parallel
    - Series
    - Network
    - Parallel-Series
    - Series-Parallel

Container Inspection

Series decision function

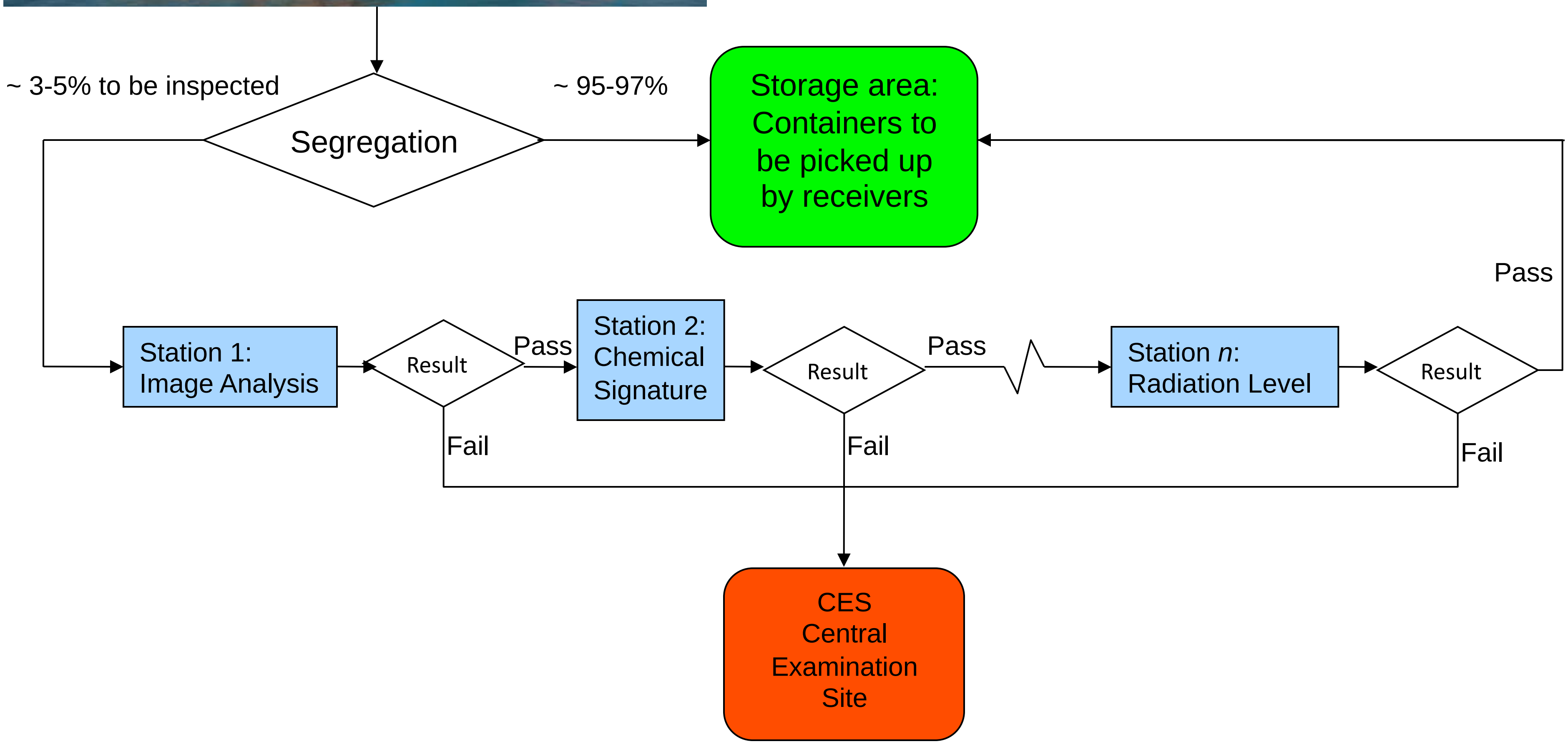


Image retrieved from <http://www.purchasing.com/articles/images/PUR/20081111/Maersk.jpg>

Container Inspection

Parallel decision function

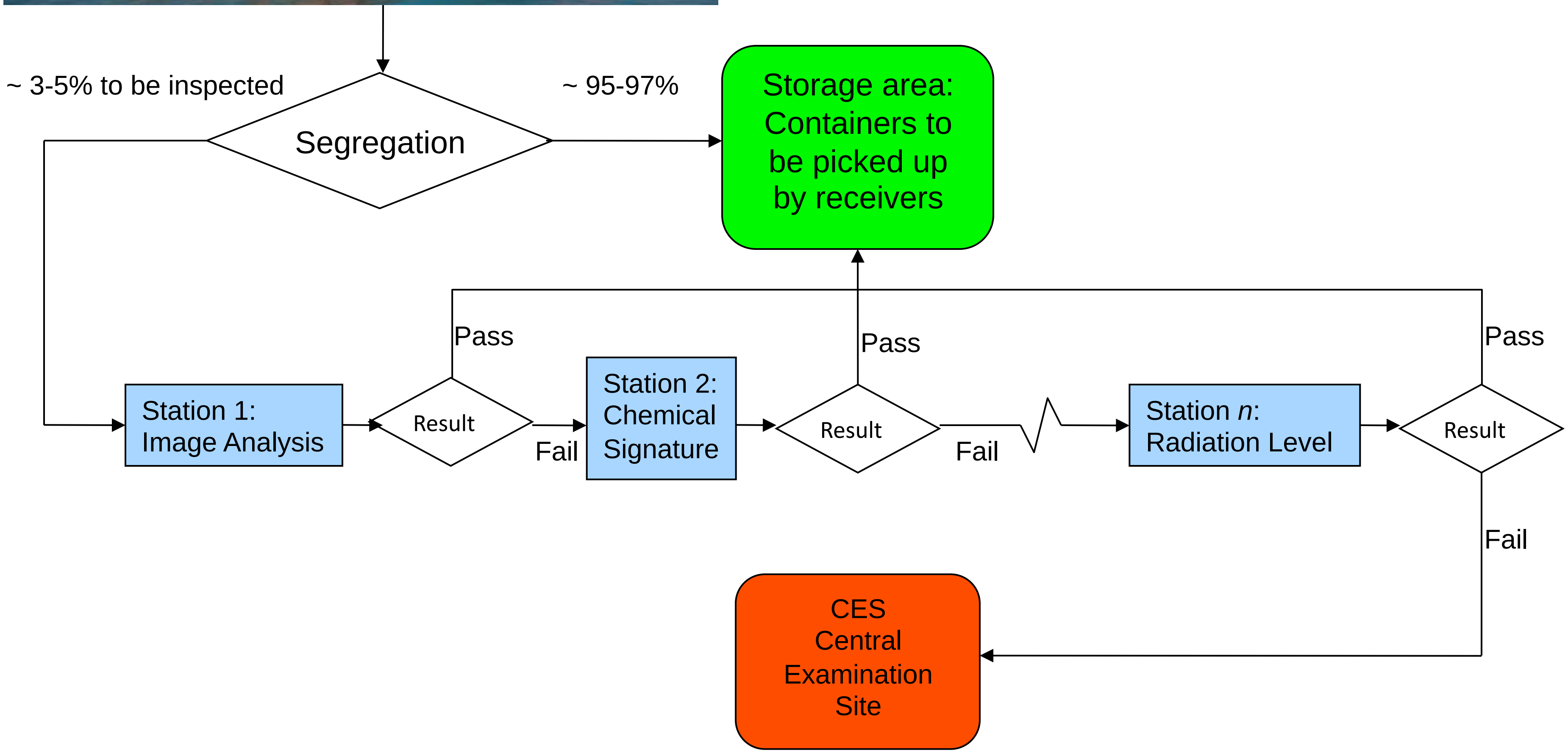
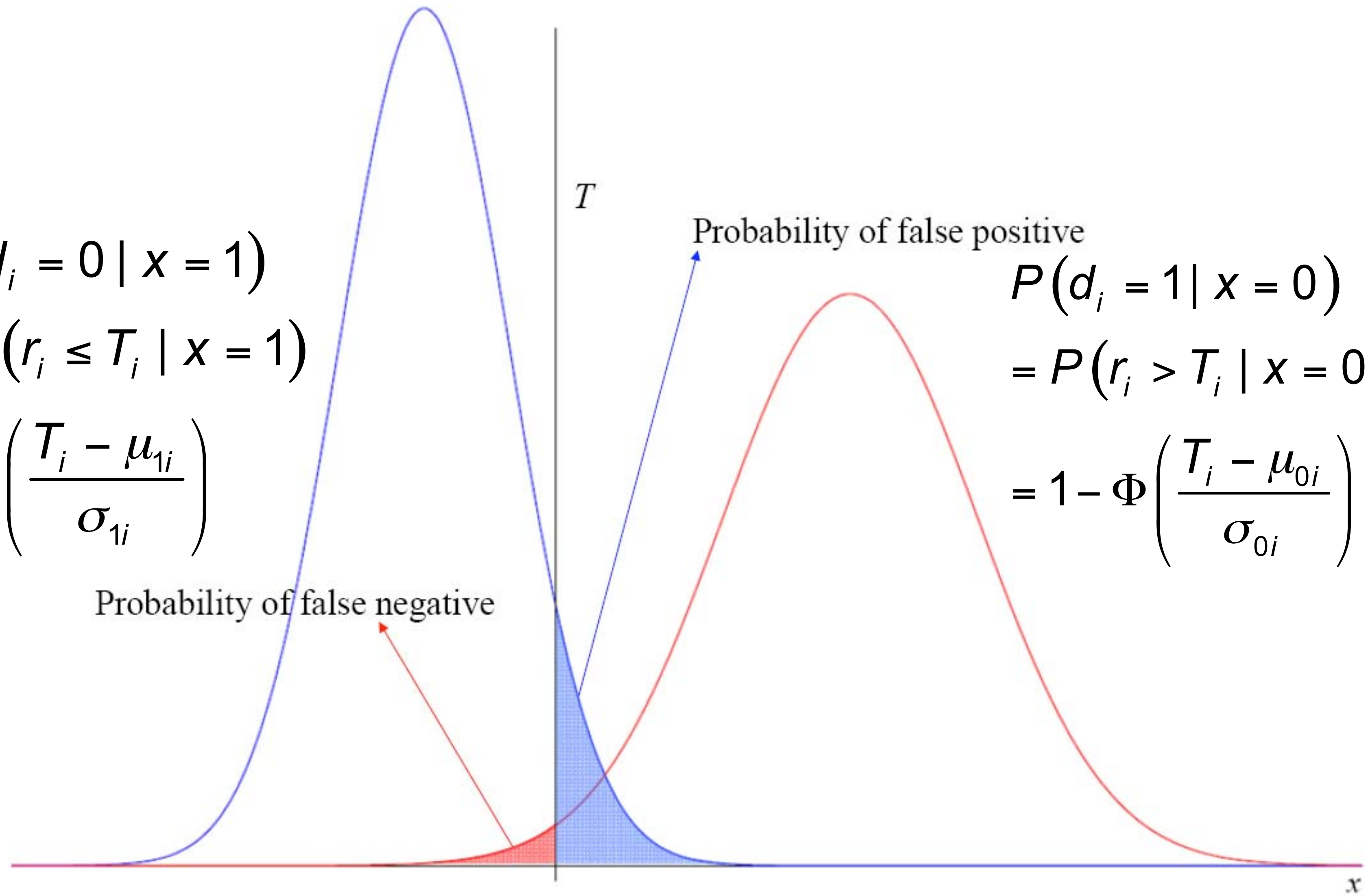


Image retrieved from <http://www.purchasing.com/articles/images/PUR/20081111/Maersk.jpg>

Simple Probabilities of Error

$$P\left(d_i = 0 \mid x = 1\right) = P\left(r_i \le T_i \mid x = 1\right) = \Phi\left(\frac{T_i - \mu_{1i}}{\sigma_{1i}}\right)$$

$$P\left(d_i = 1 \mid x = 0\right) = P\left(r_i > T_i \mid x = 0\right) = 1 - \Phi\left(\frac{T_i - \mu_{0i}}{\sigma_{0i}}\right)$$



Shielding of Special Nuclear Materials In the POE Detection Problem

235 92 U Double click for more

JP	7/2-	
Delta (MeV)	40.9205	
Abundance	0.7204 % 6	
Decay	100 α	
	7E-9 2 EC	
	8E-10 β-3n	
	8E-10 4 β++ EC	
	~ 8E-10 25Ne	

Radiations

Type	keV	%
α	4596.4	5.0
	4556.0	4.2
	4502.0	1.70
γ	185.715	57.2
	143.760	10.96

Thermal cross section (barn)

σ γ 98.8 8

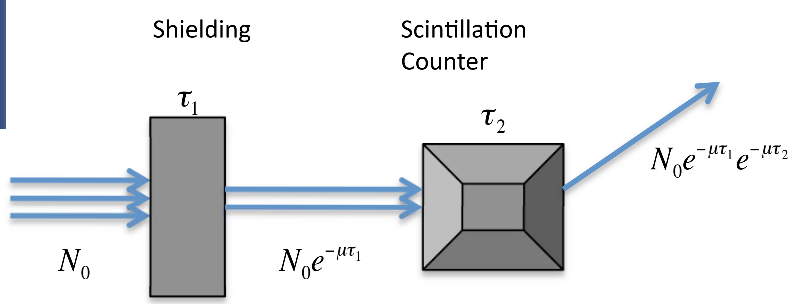
σ f 582.6 11

246 94 Pu Double click for more

JP	0+
Delta (MeV)	65.3952
Half life	10.84 2 d
Decay	100 EC+ β+

Radiations

Type	keV	%
β-	401	1.0
	177	91
γ	43.810	25
	223.750	24



Number of detected gamma-rays: $N_0 e^{-\mu\tau_1}\left(1-e^{-\mu\tau_2}\right)$

$\Leftrightarrow \quad \lambda e^{-\mu\tau}$

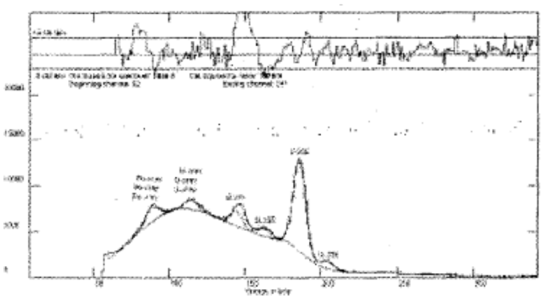


Figure 3. Fit of the unattenuated ^{235}U spectrum.

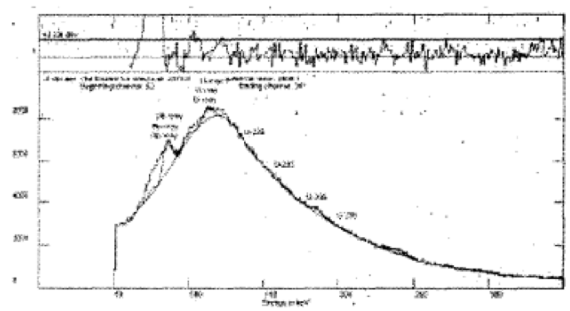


Figure 7. Fit of ^{235}U spectrum with 4 mm of lead shielding.

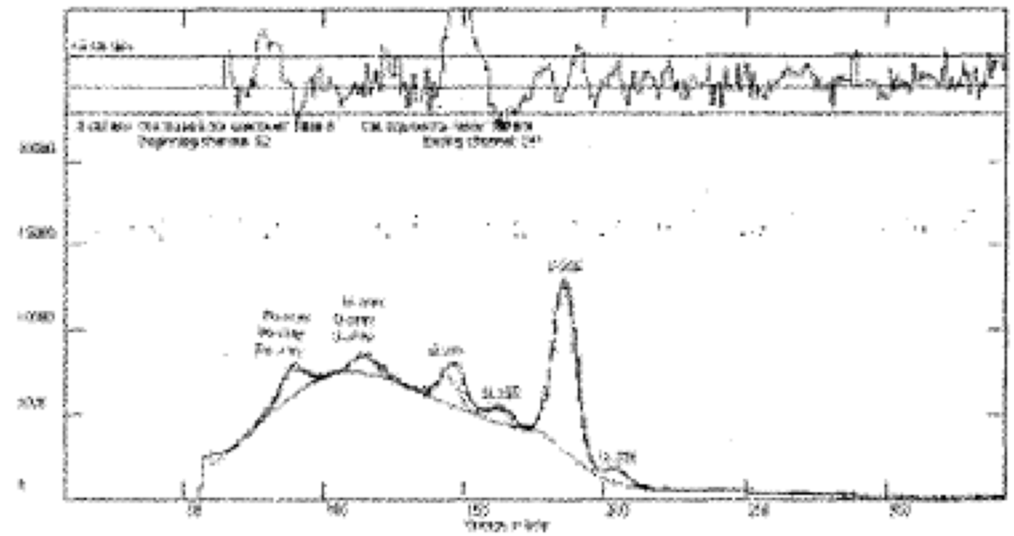


Figure 3. Fit of the unattenuated ^{235}U spectrum.

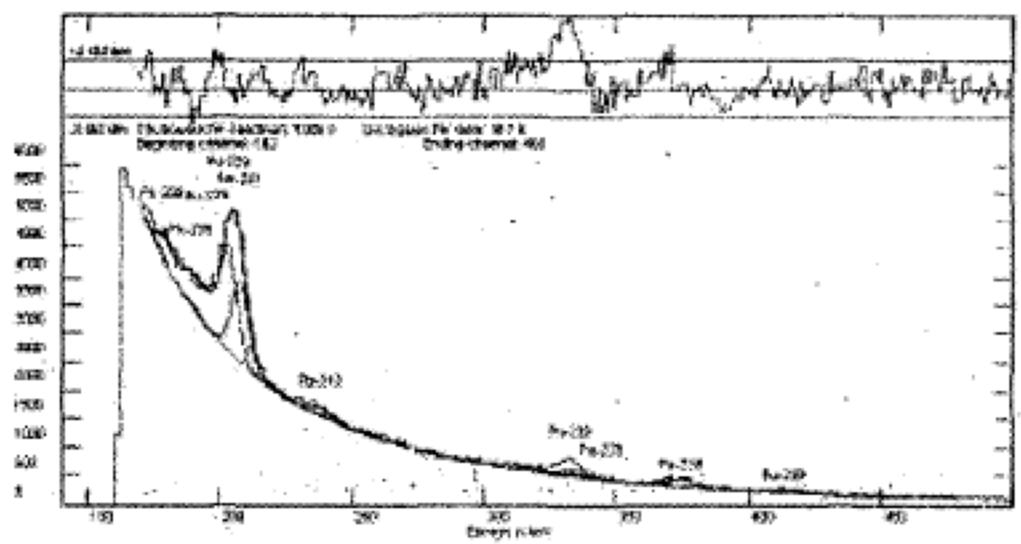


Figure 9. Fit of the unattenuated ^{239}Pu spectrum.

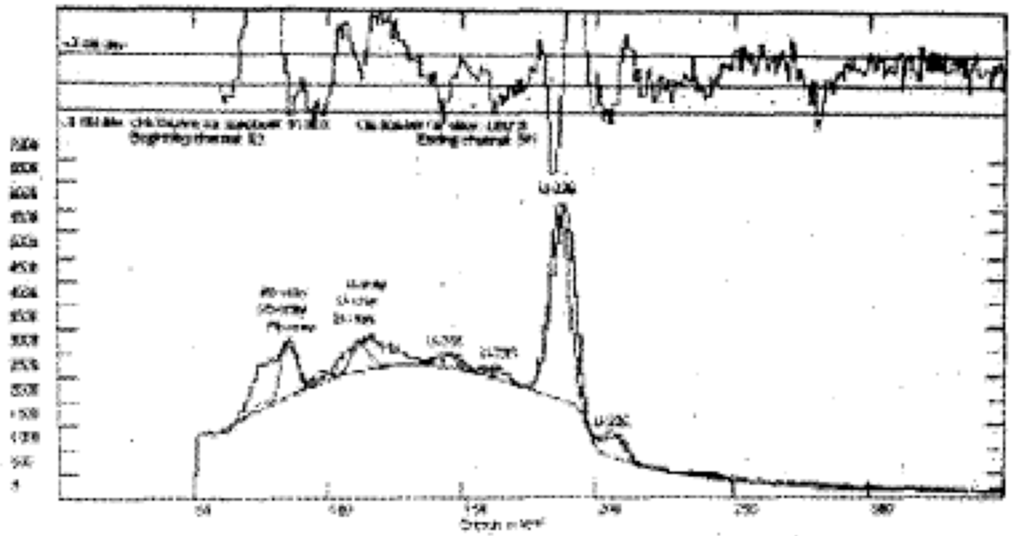


Figure 4. Fit of ^{235}U spectrum with 1 mm of lead shielding.

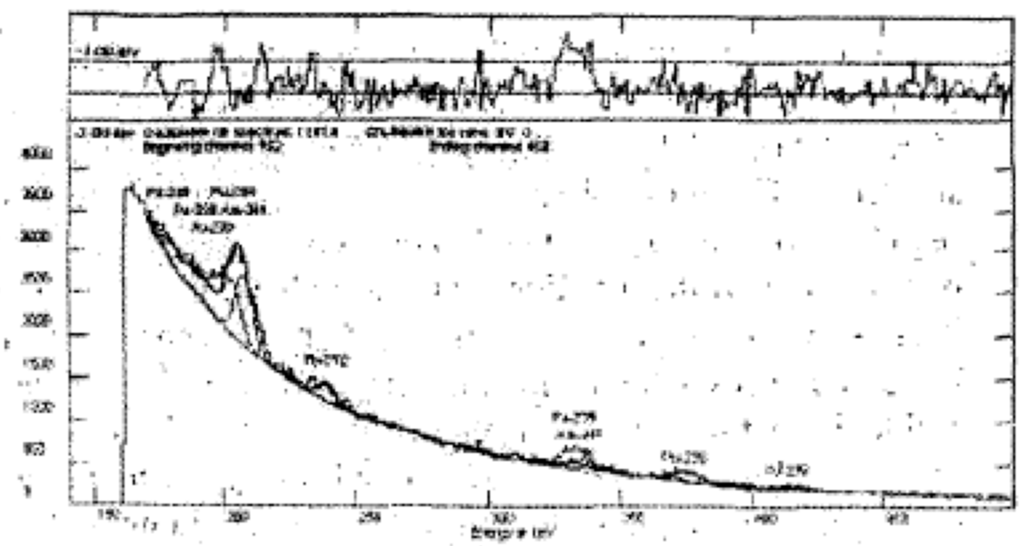


Figure 10. Fit of ^{239}Pu spectrum with 1 mm of lead shielding.

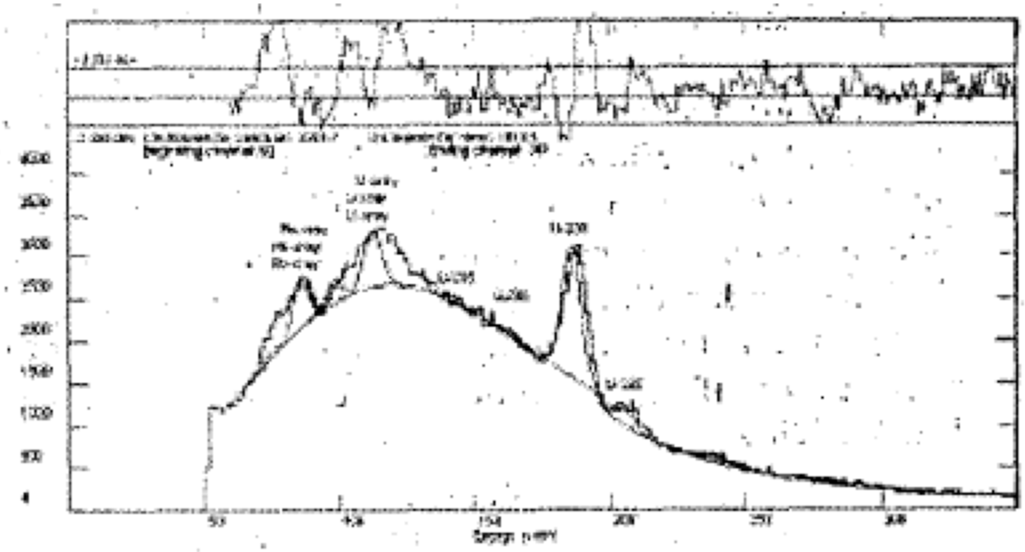


Figure 5. Fit of ^{235}U spectrum with 2 mm of lead shielding.

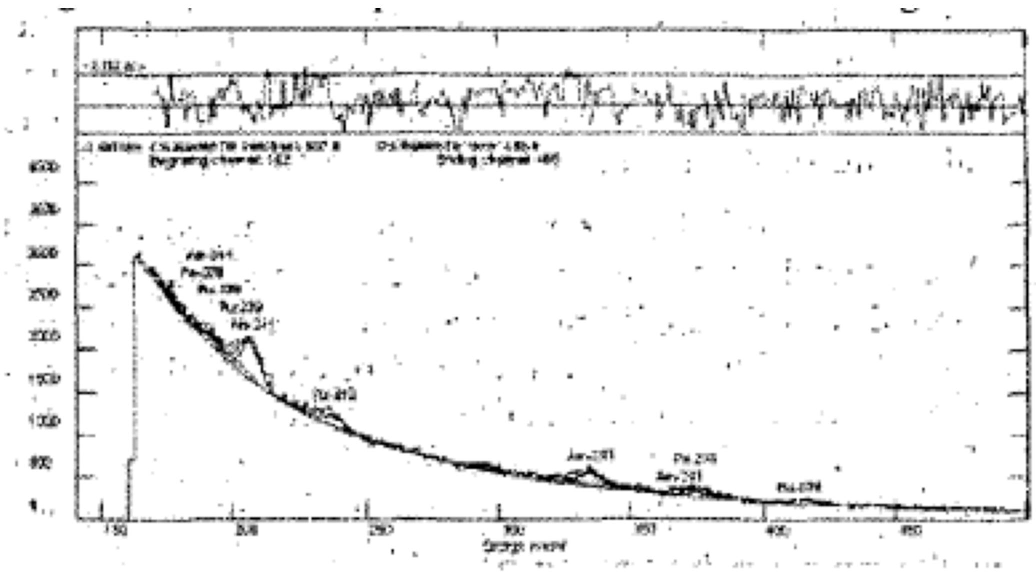


Figure 11. Fit of ^{239}Pu spectrum with 2 mm of lead shielding.

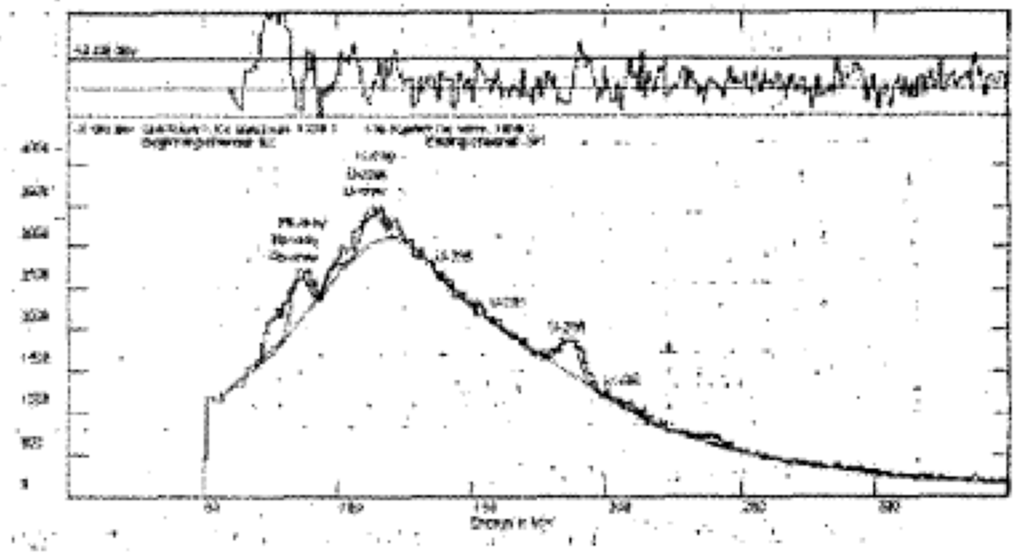


Figure 6. Fit of ^{235}U spectrum with 3 mm of lead shielding.

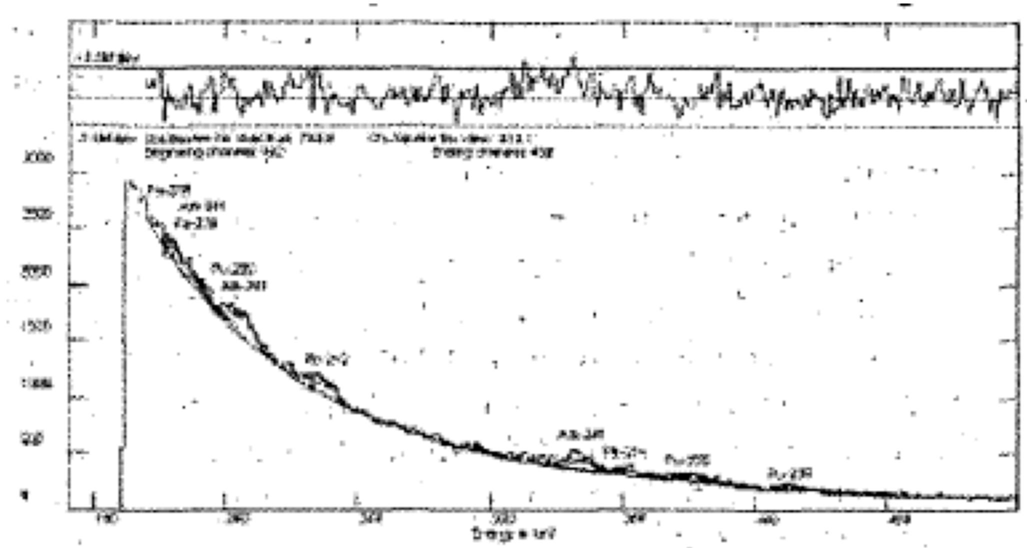


Figure 12. Fit of ^{239}Pu spectrum with 3 mm of lead shielding.

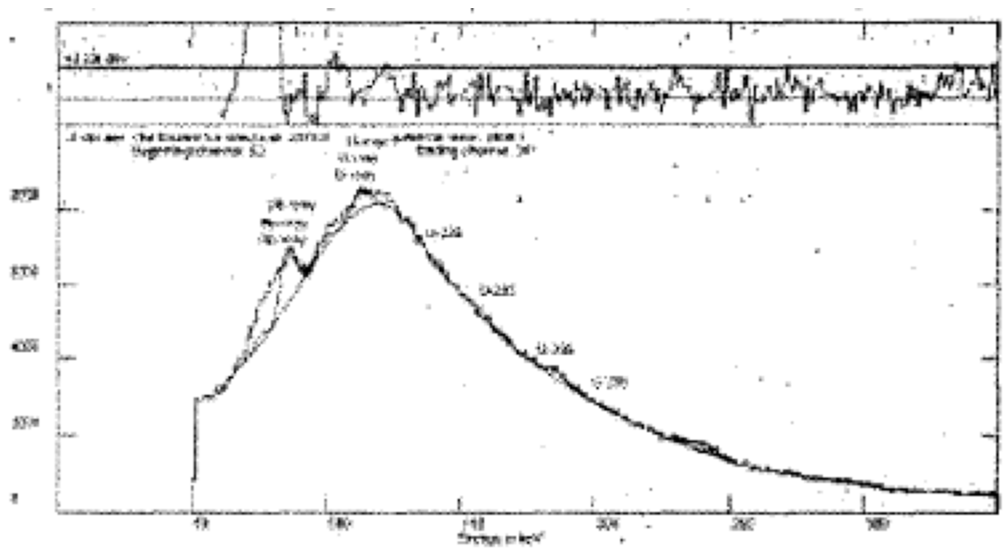


Figure 7. Fit of ^{235}U spectrum with 4 mm of lead shielding.

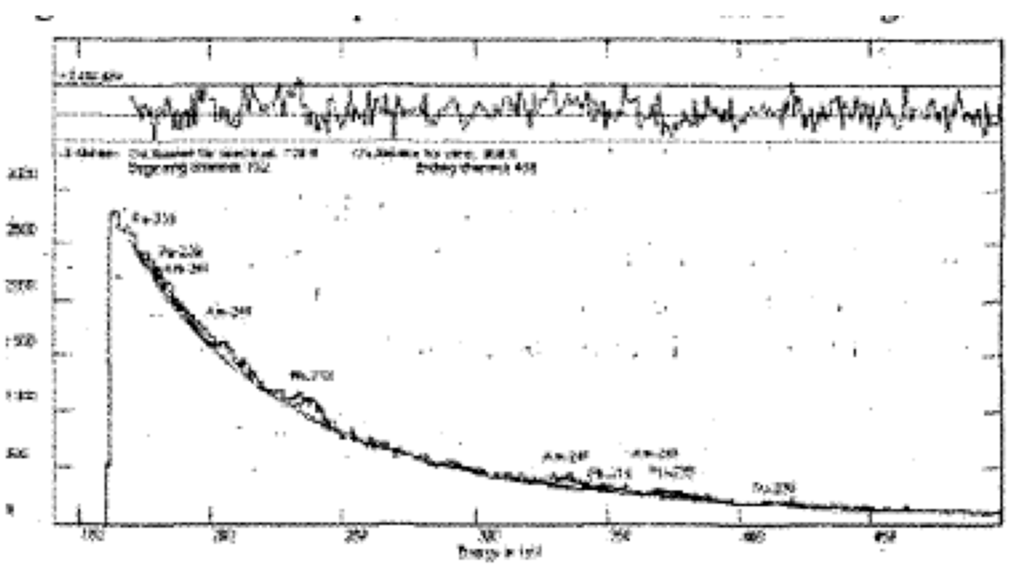
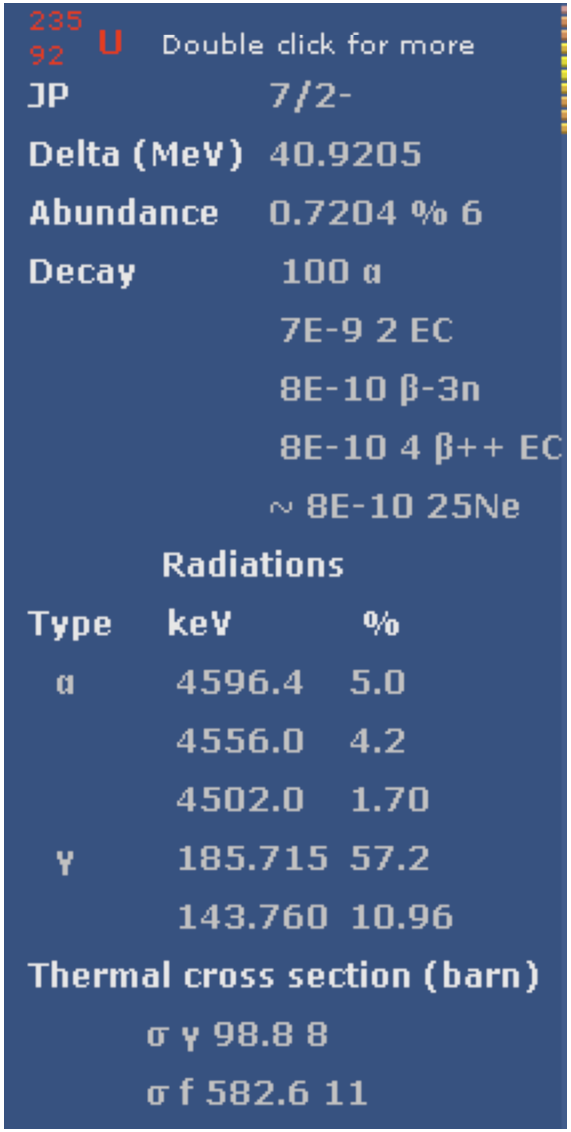
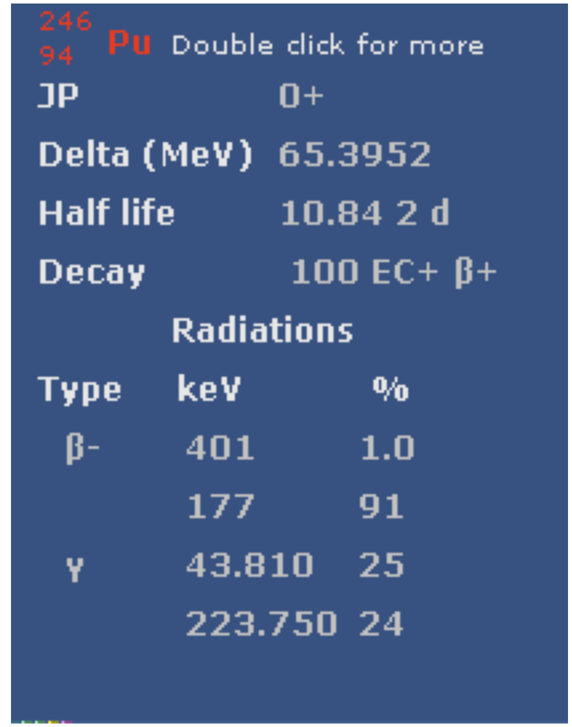


Figure 13. Fit of ^{239}Pu spectrum with 4 mm of lead shielding.

>As you can see, lead is an easily obtainable, affordable, efficient, and effective means of stopping most of the gamma radiation from SNMs

Emissions Breakdown

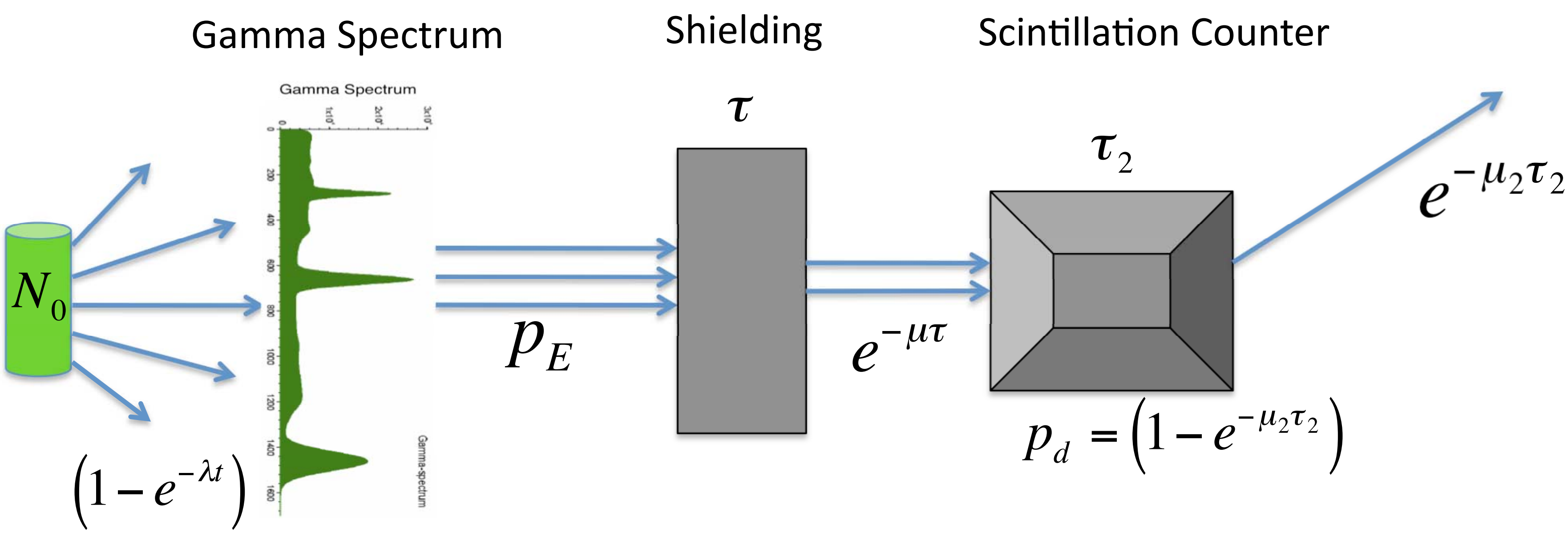




>Gamma radiation is the main type of detectable radiation for U and Pu (SNM)

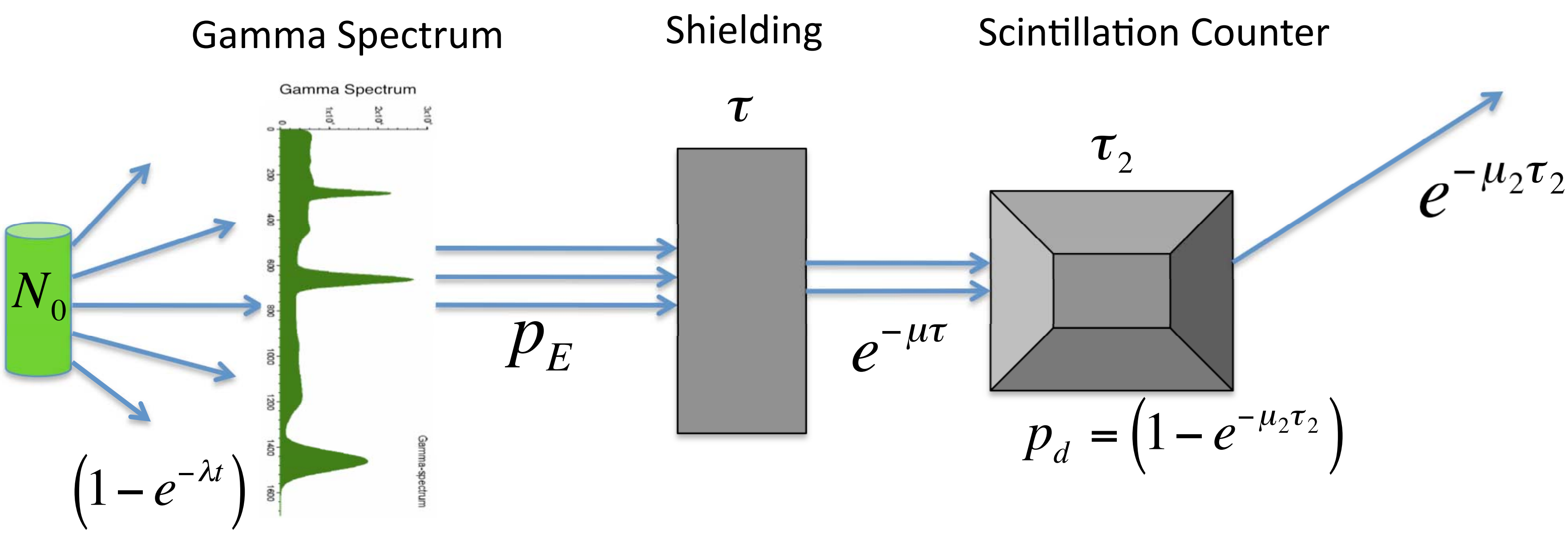
>However, it is largely lower energy gamma rays, and hence easy to stop

Detection Process



$$N_{obs} = N_0\left(1 - e^{-\lambda t}\right) p_E \, p_d \cdot e^{-\mu\tau}$$

Modeling Approach



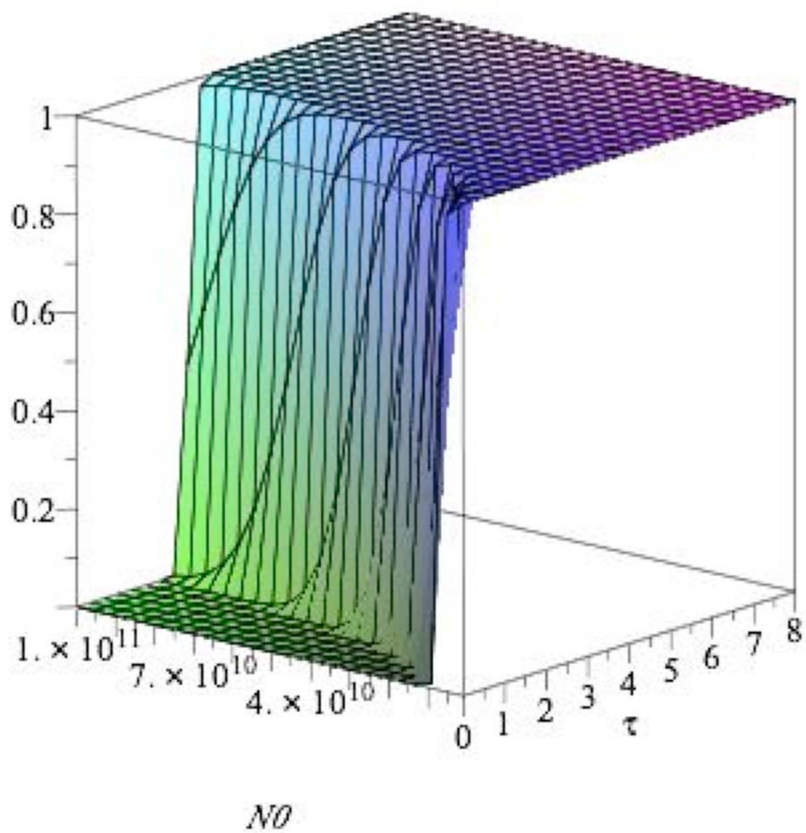
$$N_{emitted} \sim Poisson\left(N_0(1-e^{-\lambda t})\right)$$

$$\Rightarrow \quad N_{obs} \sim Poisson\left(N_0(1-e^{-\lambda t})\,p_E\,p_d \cdot e^{-\mu\tau}\right)$$

> We view N_0 and τ as parameters and investigate the relationship between the the number of observed particles, the source mass, and the shielding thickness

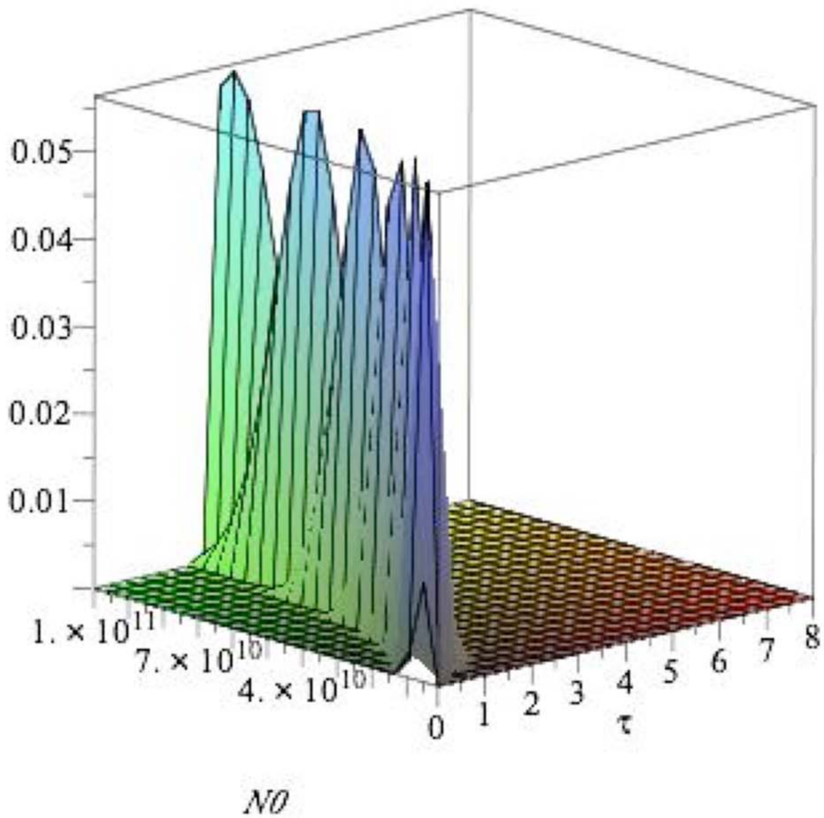
Preliminary Results

CDF of N_{obs} for 100 counts

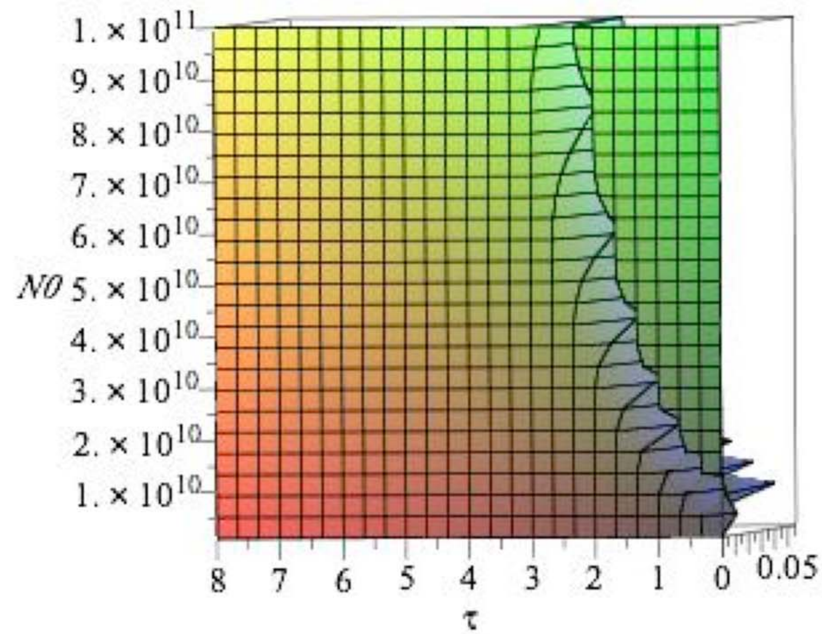


Preliminary Results

Top



Bottom



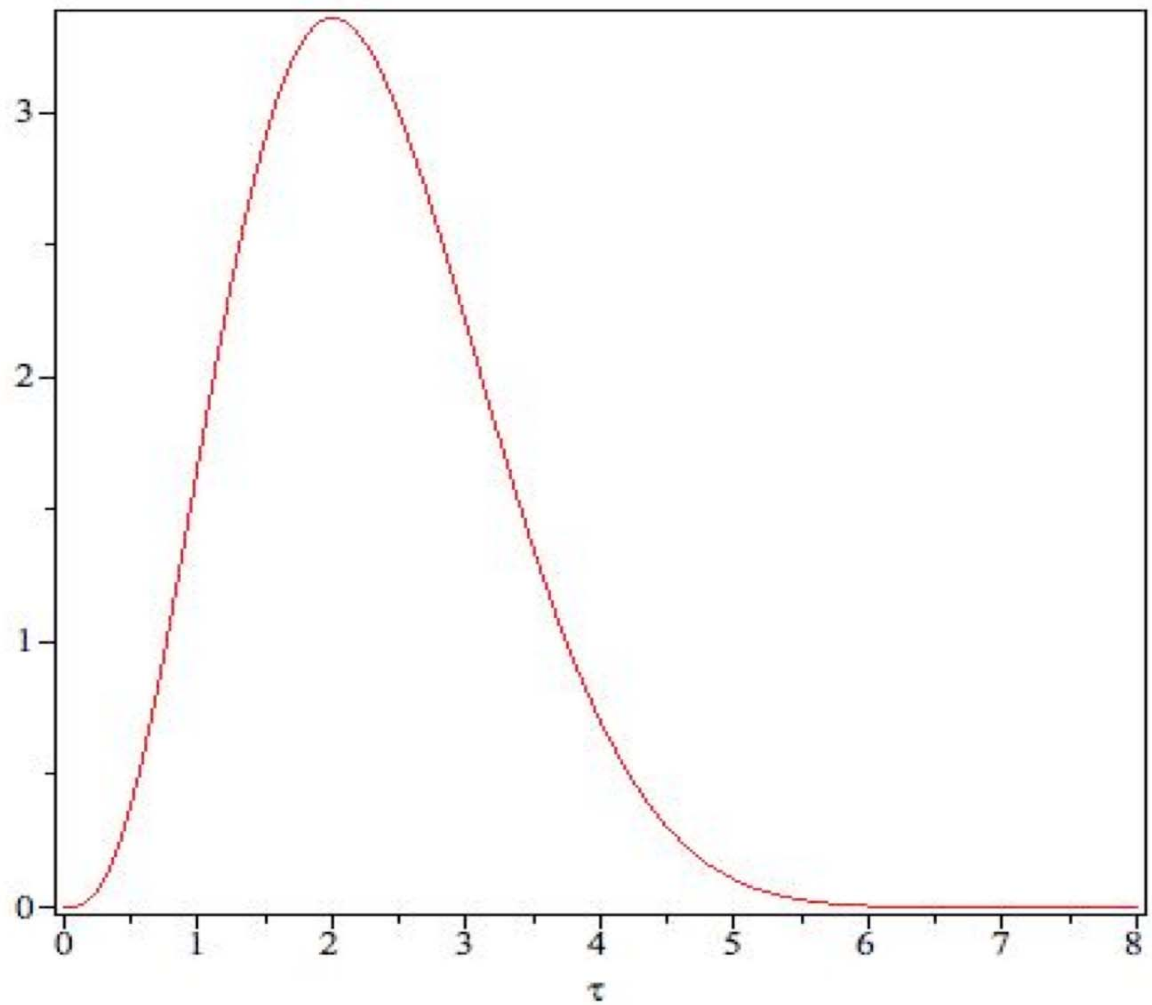
PDF of N_{obs} for 100 counts

Detection Algorithm

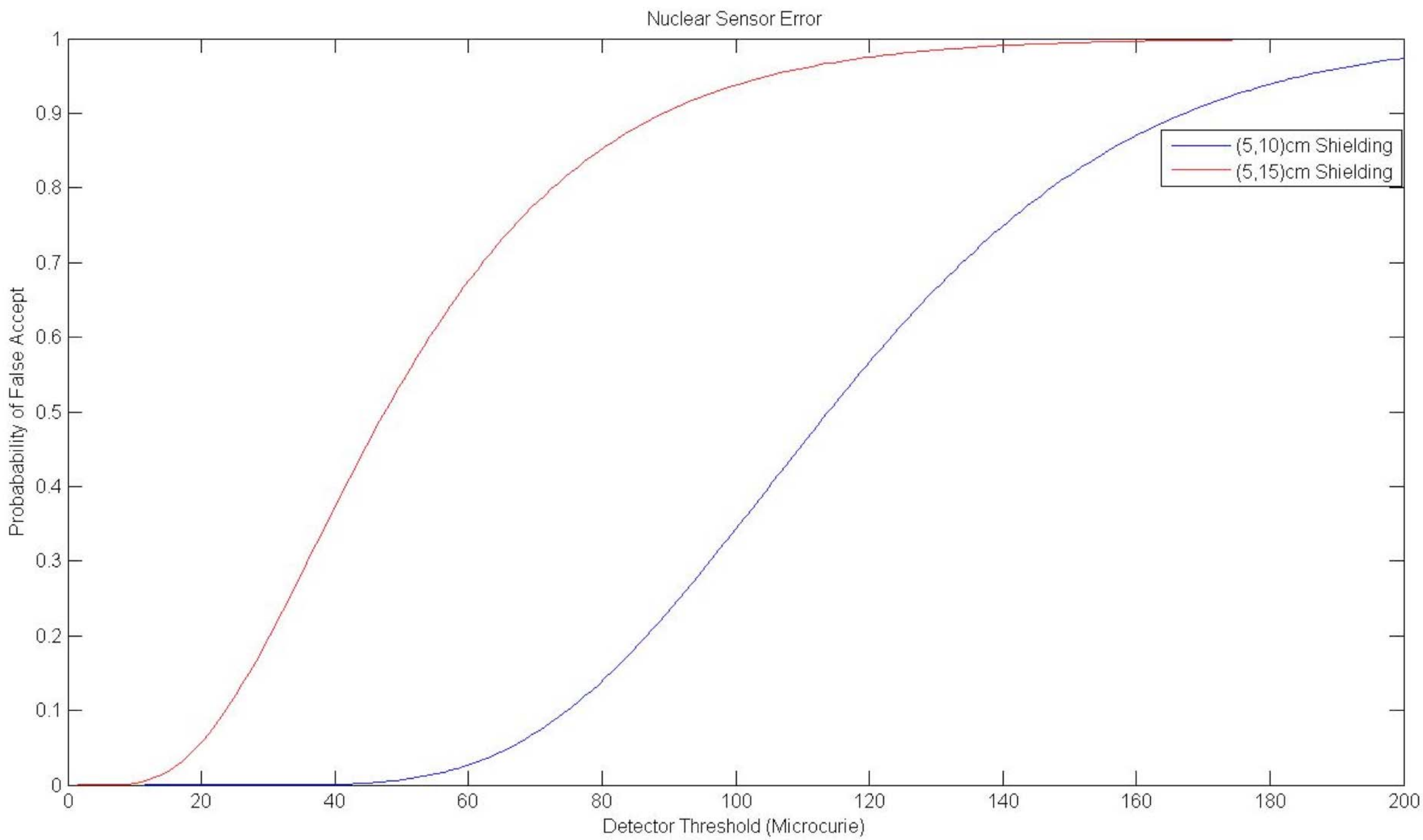
- Given an emissions count N*obs,* if we can estimate the shielding thickness (via active gamma radiography, an x-ray sensor, etc.) we have a density function for the source mass
- We can then use this density function in an improved detection algorithm that reduces misclassification error

Distributions

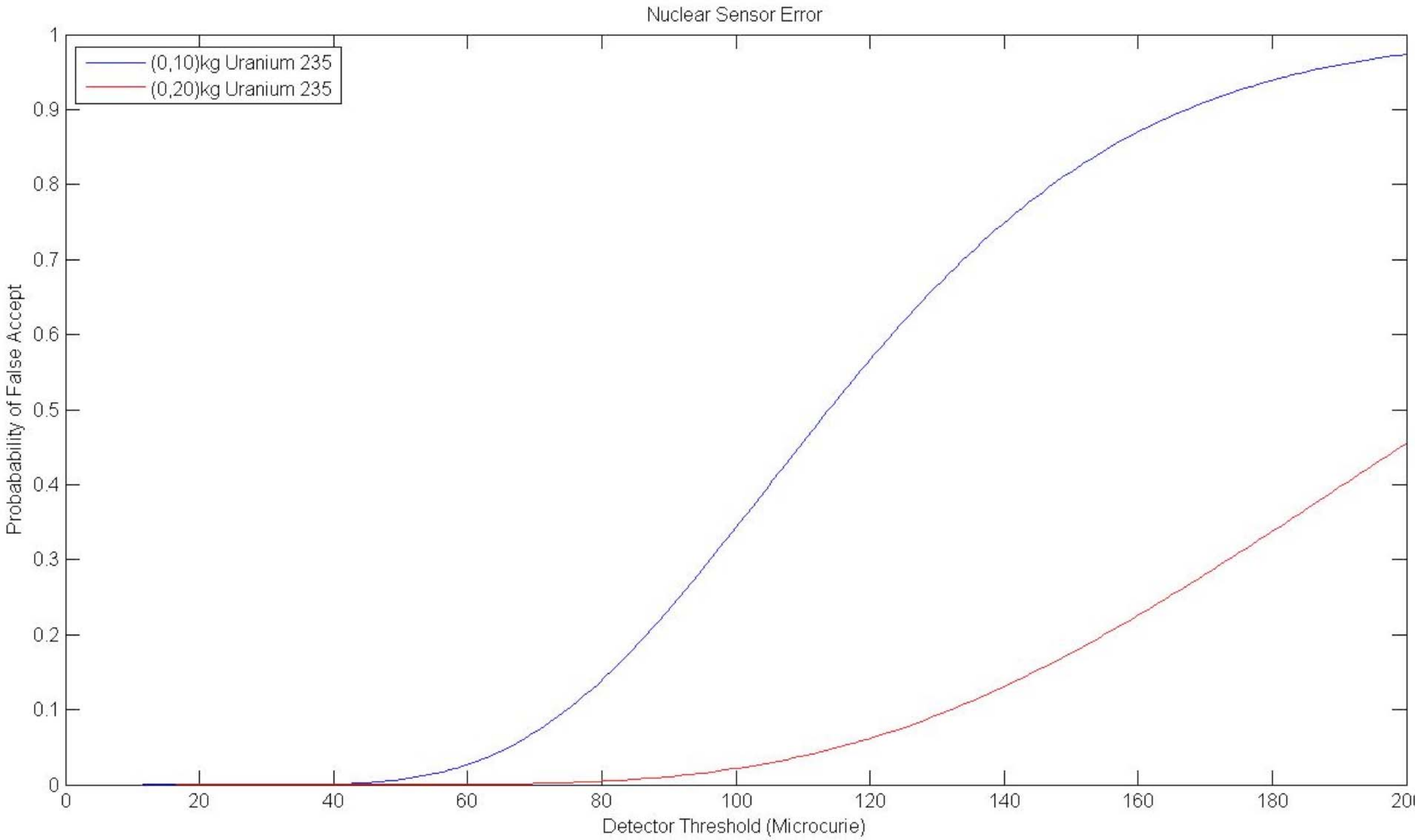
Beta Distribution for Shielding Thickness



Better Results



Better Results



Next Steps

- Use the background radiation spectrum to construct the "good" distribution for cargo containers
- Use the same optimization approach as before (with the new distributions) to optimize the sensor threshold level to minimize the expected cost

Acknowledgment and Website

- I would like to thank my mentors Dr. Elsayed and Dr. Xie, as well as Christina Young, Yada Zhu, Tsvetan Asamov, and the other members of the POE research group.
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- For further information and related papers, please visit the DIMACS website

  http://dimacs.rutgers.edu/Workshops/PortofEntry