Using Low-resolution Gamma-ray Spectroscopy and Machine Learning as an Information Barrier for Uranium Enrichment Measurements

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Consortium for Verification Technology (CVT), June 2019

Introduction and Motivation

- **Goal:** Algorithmically quantify **uranium enrichment** in unknown **radiation background fields** and **NaI(Tl) detector calibrations.**

- **Motivation:**
  - **Nondestructive U-enrichment measurements** enable **nonproliferation**, **treaty verification**, & **homeland security.**
  - Well-trained Artificial Neural Networks (ANN) may be able to perform **single attribute measurements** (i.e. **uranium enrichment**) in safeguards scenarios **without the intervention of a spectroscopist.**
  - **Handheld 2" x 2" NaI(Tl)** detectors provide an **information barrier** due to inherent **low-resolution.**
  - ANNs trained on simulated spectra have demonstrated **good performance** in automated NaI ɣ-ray spectroscopy tasks [1].

Parameter	Simulated Range
Isotopes	[^{235}U, ^{238}U, ^{232}U]
Energy	[0 - 3 MeV]

Table 1: ɣ-spectrum templates simulated with MCNP

Parameter	Simulated Range	Distribution
Enrichment	[0%, 100%]	uniform
Calibration Gain	[0s, 3600s]	log-uniform
Integration live time	[0s, 3600s]	log-uniform
Uranium Mass (m_U)	[100g, 30kg]	log uniform

Table 2: Training dataset (10^5 spectra)

Methods

We **simulated a dataset** of ɣ-spectra and **trained machine learning algorithms** to perform **uranium enrichment measurements** without prior knowledge of the **background radiation field** and **detector calibration.**

1. Simulated **ɣ-spectrum** templates of **key isotopes** in reprocessed enriched uranium with **MCNP (Table 1)**
2. Used **LLNL** open source package **RadSrc** to calculate the **intrinsic ɣ-ray spectrum** from the nuclear decay of a mixture of radioisotopes.
3. Generated training dataset **(Table 2)** with background spectra from GADRAS templates.
4. **Optimized** a **Dense Neural Network** (DNN) architecture using a **random hyperparameter search** [2].

Results Description

10 DNNs were applied to **HEU** spectra measured using a 2" x 2" NaI(Tl) detector at the **Device Assembly Facility (Figure 1).**

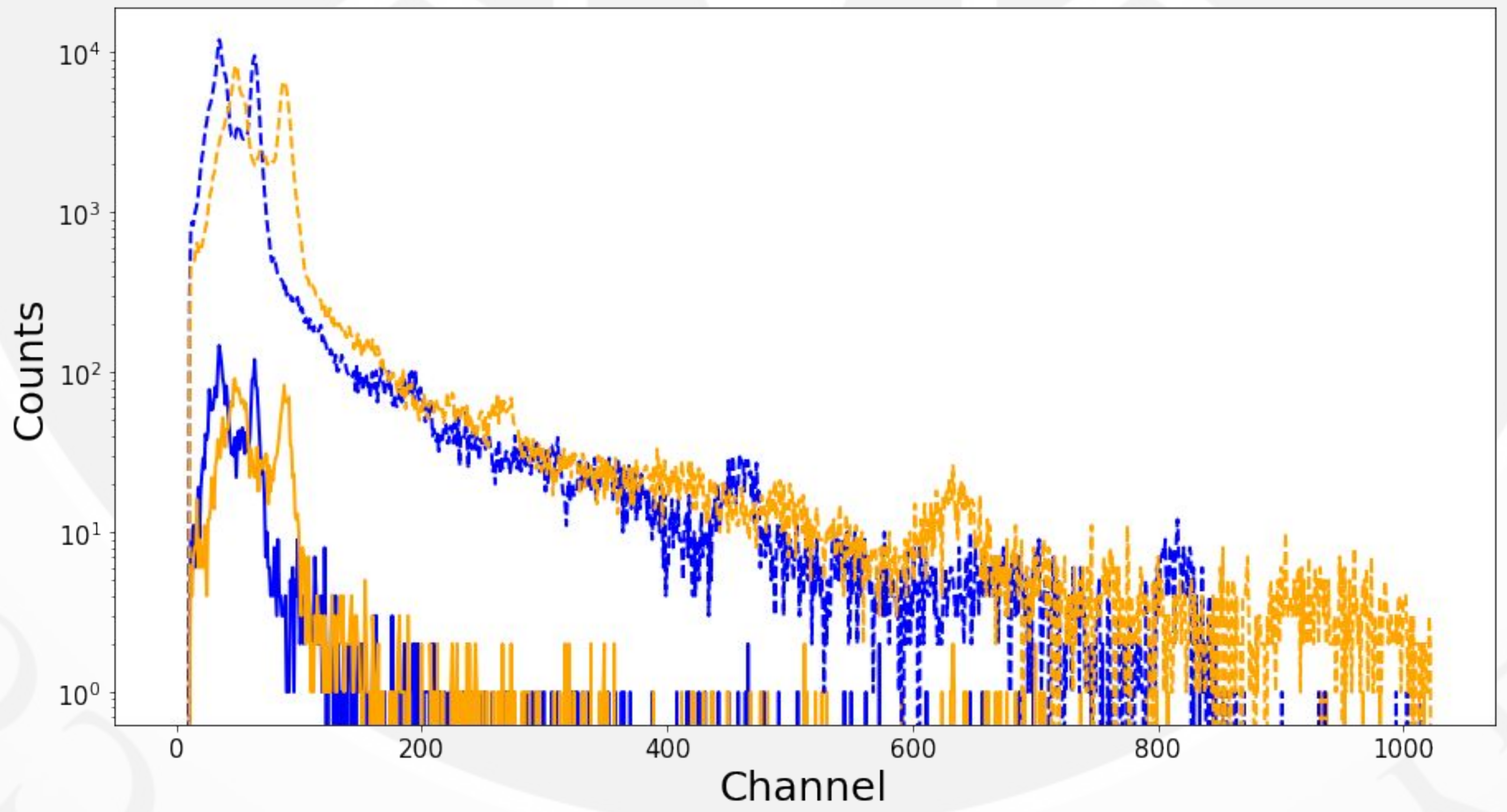

Figure 1. HEU **(93%)** spectra measured at the DAF. Solid lines are measured with a live time of 5 seconds, dotted lines for 750 seconds. Orange and blue lines show two different gain settings.

Results and Discussion

- The DNN ensemble demonstrated a **high bias** on the measured spectra, likely due to:
  - Differences between simulated training data and real spectra
  - Inherent low-resolution of NaI(Tl)

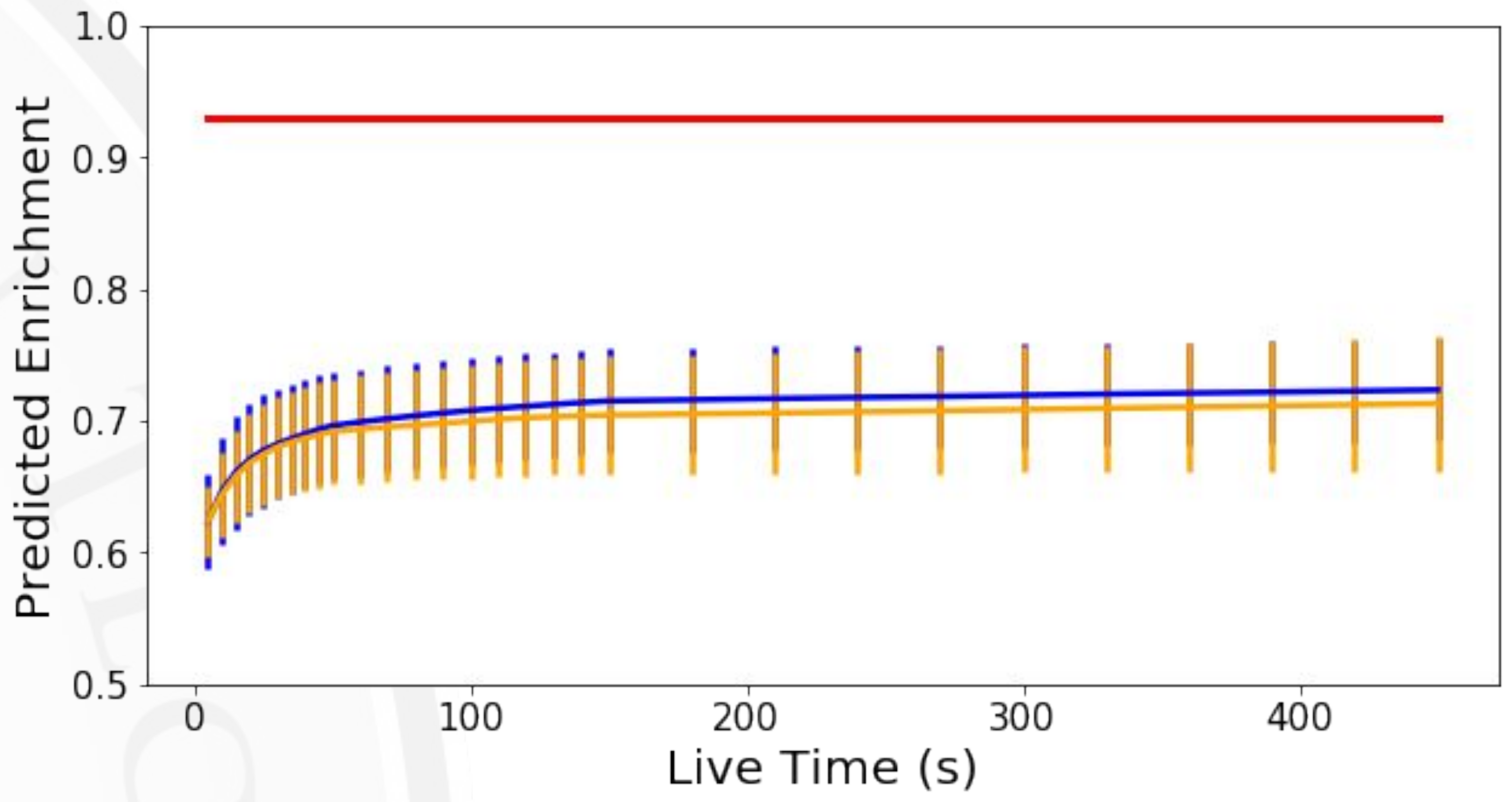

Figure 2. DNN ensemble prediction of uranium enrichment for two gain settings shown in Figure 1. Red line is at the correct enrichment of 93%.

Conclusion

- Current simulated training dataset is **not accurate enough** for useful **automated uranium enrichment** measurements
- Future steps:
  - Improve accuracy of simulated training dataset
  - Apply method to measured NaI spectra of **more enrichment levels**
  - Investigate the effect of adding **shielding** to the training set
  - Investigate **plutonium isotopic** measurements with **unknown shielding** and **scattering environments** with low- and medium-resolution detectors

[1] M. Kamuda, J. Stinnett, and C. J. Sullivan, "Automated Isotope Identification Algorithm Using Artificial Neural Networks," *IEEE Transactions on Nuclear Science*, vol. 64, no. 7, pp. 1858–1864, Jul. 2017, https://doi.org/10.1109/TNS.2017.2693152.
[2] J. Bergstra and Y. Bengio, "Random Search for Hyper-Parameter Optimization," *Journal of Machine Learning Research*, vol. 13, no. Feb, pp. 281–305, 2012.

This work was funded in-part by the Consortium for Verification Technology under Department of Energy National Nuclear Security Administration award number DE-NA0002534