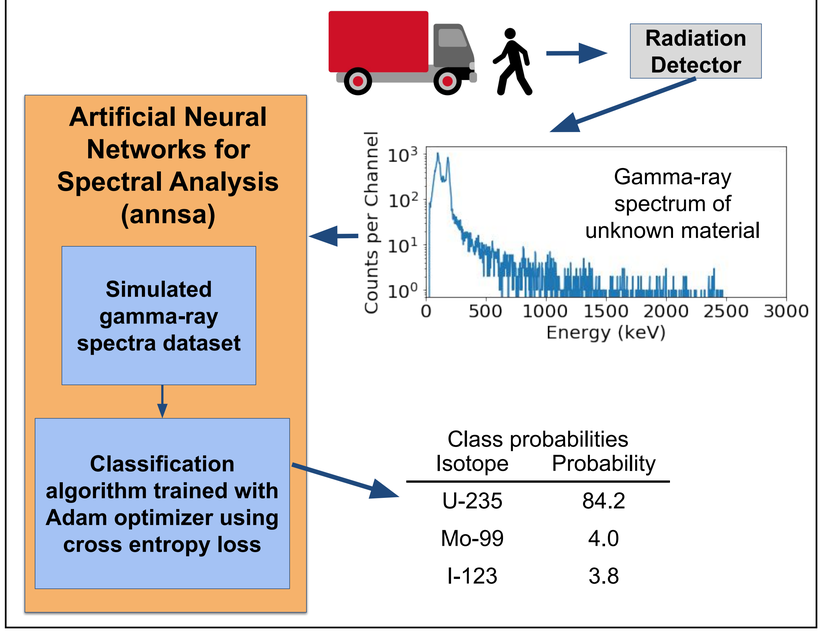
Preventing Disaster: Identifying Nuclear Weapons with Neural Networks

Mark Kamuda, Professor Kathryn Huff
University of Illinois at Urbana-Champaign

Introduction

- Goal: develop a radioisotope identification algorithm that can operate without prior knowledge of the **background radiation field**, **detector calibration, source shielding,** and **scattering environment.**



Class probabilities

Isotope	Probability
U-235	84.2
Mo-99	4.0
I-123	3.8

Method

- **Problem specific** gamma-ray spectra datasets are **simulated**:
  - Source interdiction
  - Measuring uranium enrichment
- Tensorflow used to optimize and train **dense**, **convolution**, and **autoencoder** models using **online** or **offline data augmentation**
  - Random hyperparameter search implemented to optimize **architecture** and **training hyperparameters**
- **Simulated** and **measured** spectra datasets used to benchmark and compare algorithms
- **annsa** Source code: https://github.com/arfc/annsa
- Relies on many scientific Python packages
  - TensorFlow, scikit-learn, numpy, Jupyter, and many others

Simulated Training Dataset

- Spectra can be **augmented online** or **offline** to change:
  - Detector calibration
  - Isotope mixture in each spectrum
    - Isotopes from the ANSI N42.34 used for source interdiction
  - Measurement time
  - Standoff distance
  - Radioactive source strength
  - Background radiation composition
- Shown below are **training examples** and **convolution neural network identification results**

U-235
Special Nuclear Material

Isotope	Probability
U-235	96.5
Tl-201	1.6
Lu-177m	1.1

Ga-67
Medical

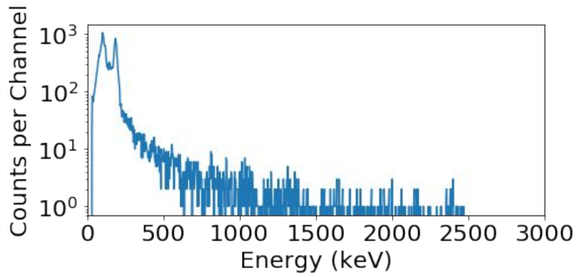
Isotope	Probability
Ga-67	98.9
Np-237	0.4
Tl-201	0.3

Ba-133
Medical

Isotope	Probability
Ba-133	90.9
Np-237	3.5
Cr-51	2.3

Identification Example - High Enriched Uranium

- 93% enriched 14 kg uranium sphere measured with a 2''x2'' NaI detector
- Results show convolution neural networks **consistently outperform** dense architectures



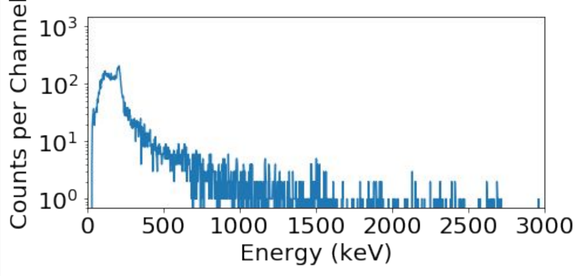
High enriched uranium

Convolution Neural Network

Isotope	Probability
U-235	84.2
Mo-99	4.0
I-123	3.8
Tl-201	2.3
Tc-99m	2.0

Dense Neural Network

Isotope	Probability
U-235	88.1
I-123	6.5
In-111	1.9
Ga-67	1.6
Mo-99	0.5



High enriched uranium shielded by 0.5 inches of iron

Convolution Neural Network

Isotope	Probability
U-235	58.7
Lu-177m	23.6
In-111	16.2
Background	2.3
Mo-99	2.0

Dense Neural Network

Isotope	Probability
In-111	72.1
U-235	10.8
Mo-99	5.4
Ga-67	3.4
I-123	3.2

This work was funded by the Consortium for Verification Technology under Department of Energy National Nuclear Security Administration award number DE-NA0002534. Additionally, the authors are grateful to Dr. Clair Sullivan who was instrumental in the early stages of this work.

National Nuclear Security Administration