Statistical Methods for Pre-detonation Nuclear Forensics Analysis

Arrielle C Opotowsky, Prof. Paul PH Wilson

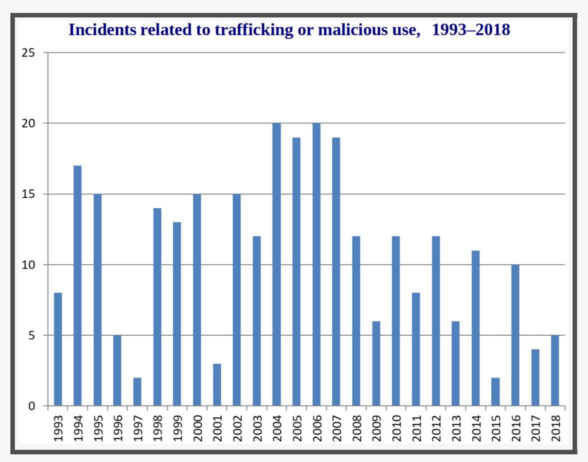
University of Wisconsin-Madison

Motivation: Speeding up nuclear emergency response

After a nuclear weapon is detonated or nuclear material is intercepted, a priority for emergency responders is to determine both where it came from and the radioactive danger to the public. While the latter can be determined quickly, the former often involves lab work that can take days or weeks.

This is part of a nuclear forensics investigation: attribution of a nuclear indicent. This informs both emergency response and what actions the government takes. A strong nuclear forensics capability both deters governments from engaging in state-sponsored nuclear terrorism and interrupts the pathways being used to create weapons.

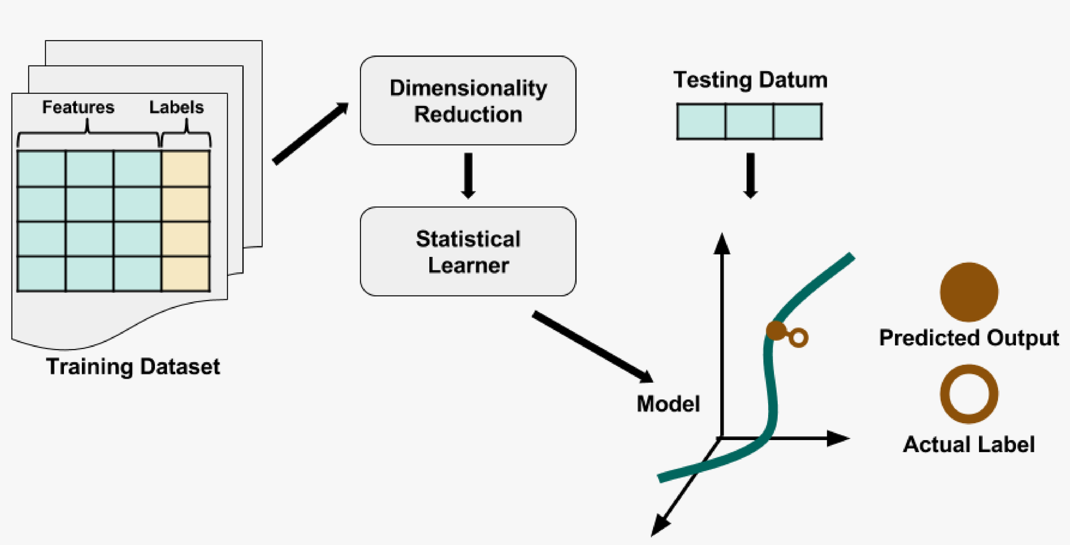
The figure shows the number of nuclear material incidents tracked in the last 25 years, of which 12 involved highly enriched uranium, 2 plutonium, and 4 plutonium-beryllium neutron sources. Thus, this work focuses on spent nuclear fuel (SNF) from reactors outside of regulatory control as a material of interest.



Participating countries (138) report intercepted nuclear materials intended for illicit use to the IAEA.[1]

Background: Using statistical methods to evaluate nuclear forensics signatures

Presented here is a methodology that seeks to rapidly provide investigation-guiding information using measurements taken in the field compared against statistical models.
this methodology can apply to any nuclear material, intact or remnants of a detonation.
Statistical methods may be able to determine reactor operation parameters faster than the traditionally utilized empirical relationships. To evaluate their utility in this context, a number of questions must be answered.
Nuclear forensics research initiatives include characterization of both pre- and post-detonation materials. Measuring isotopic ratios, chemical compounds, and trace elements are signatures used to identify the chain of custody of these materials. One such material is spent nuclear fuel (SNF) from power reactors. The analysis of this is usually focused on determining a set of reactor parameters that generated the material: reactor type, fuel enrichment, burnup, and cooling time. This provides information that can lead to the source of the material in question.
Figure 2 is blah blah blah



Caption me

Main Research Question

How does the ability to determine forensic-relevant spent nuclear fuel attributes using machine learning techniques degrade as less information is available?

Determine
The inverse problem: given end measurements, calculate the model parameters that created them

Information
Nuclide vectors, measurements of isotope ratios

Forensic-relevant Attributes
Reactor type, enrichment, cooling time, burnup

Machine Learning Techniques
Creating statistical models (not physical)

Degrade
Model prediction performance

Less Information
Error in nuclide vectors, fewer measurements, etc

Definition of terms within the main research question

Methodology: Maximum likelihood estimation for prediction

Toy training set for demonstration, describe features chosen + labels of interest Show generic ML workflow MLE method chosen for measure of uncertainty Include uncertainty?

Title2

Text2

Title3

Text3

References

[1] Incident and Trafficking Database (ITDB) Program, *IAEA Incident and Trafficking Database: 2019 Fact Sheet*, tech. rep. (International Atomic Energy Agency, Division of Nuclear Security, 2019).

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