Application of Multivariate Analysis to Gamma and Neutron Signatures from Spent Nuclear Fuel

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Outline

- Introduction
- Multivariate Analysis
- Passive neutron and gamma measurements to characterize spent fuel
- Summary and Outlook

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INTRODUCTION

Nuclear safeguards

- Nuclear materials can be used for Nuclear weapons or Nuclear Energy
- Non-proliferation treaty:
  - Non-nuclear weapon states:
    - Never acquire nuclear weapons
    - Accept IAEA safeguards
  - Nuclear weapon states
    - Share the benefits of peaceful nuclear technology
    - Further disarmament

Nuclear safeguards under IAEA

- Accountancy of nuclear materials
- The IAEA performs inspections to **verify** that the records are correct
- Continuity of Knowledge via measurements and surveillance

Source: solidwize.com

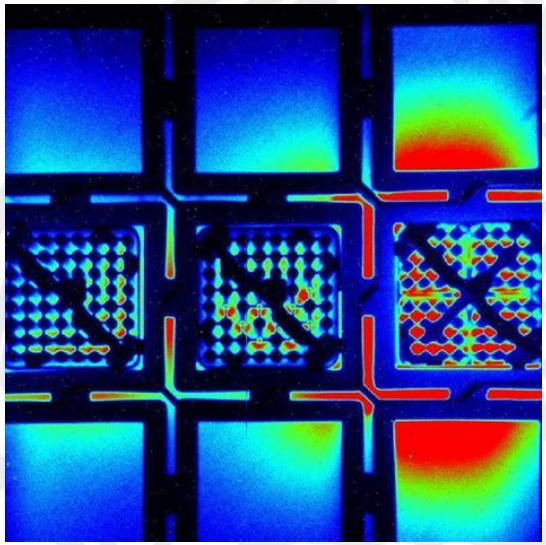
Measuring spent nuclear fuel

- **Verification** of Burnup (BU), Cooling time (CT), Initial enrichment (IE)
- Isotopic composition of fuel depends on reactor operation and fuel history

- Non-destructive measurements:

gamma, neutron, Cherenkov light

- Traditionally:
  - Separate analysis
  - In gamma, few isotopes ratios used



Source: http://nuclearsafety.gc.ca/

Our research goal

- Verify BU, CT, IE (characterization)
- Using multivariate data analysis
- With non-destructive assay
  - passive gamma: HPGe-detector
  - passive neutron: DDSI instrument
  - DCVD? Active neutron and gamma?

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MULTIVARIATE ANALYSIS

Multivariate data analysis (MVA)

- Many variables representing an object
  - **gamma emitting isotope activities, neutron signal**
- Want to predict:
  - Continuous variables (regression) – **BU, CT, IE**

- Train computers with different models on known data
- Test on other known data
- Predict unknown data

- So far: only simulated PWR 17x17 assemblies

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PASSIVE NEUTRON AND GAMMA MEASUREMENTS TO CHARACTERIZE SPENT FUEL

Motivation

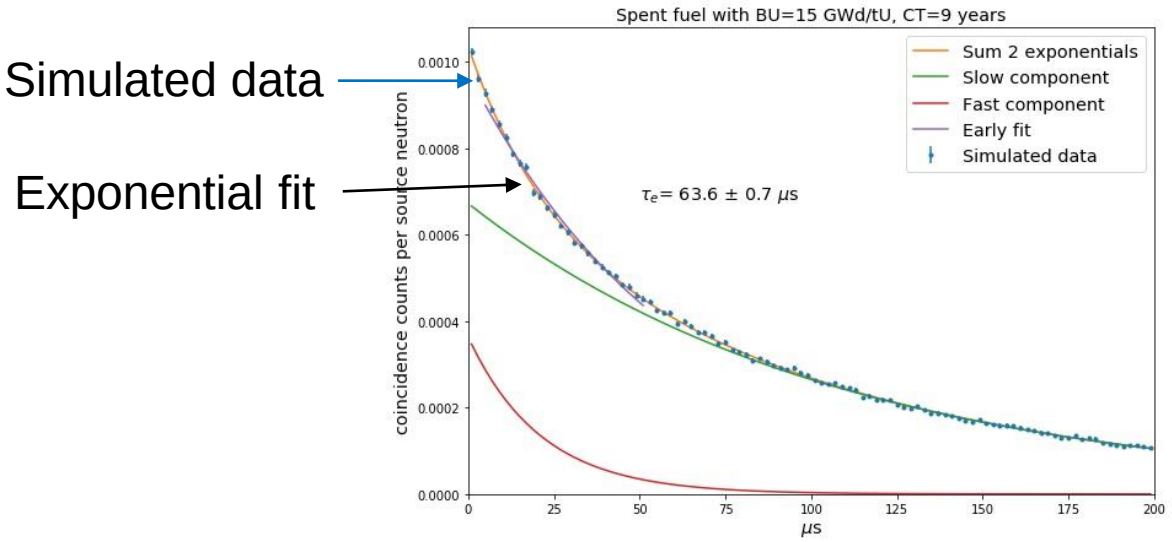
- BU, IE and CT with only passive gamma spectroscopy only up to 20 y CT
- What if we add a neutron signature?

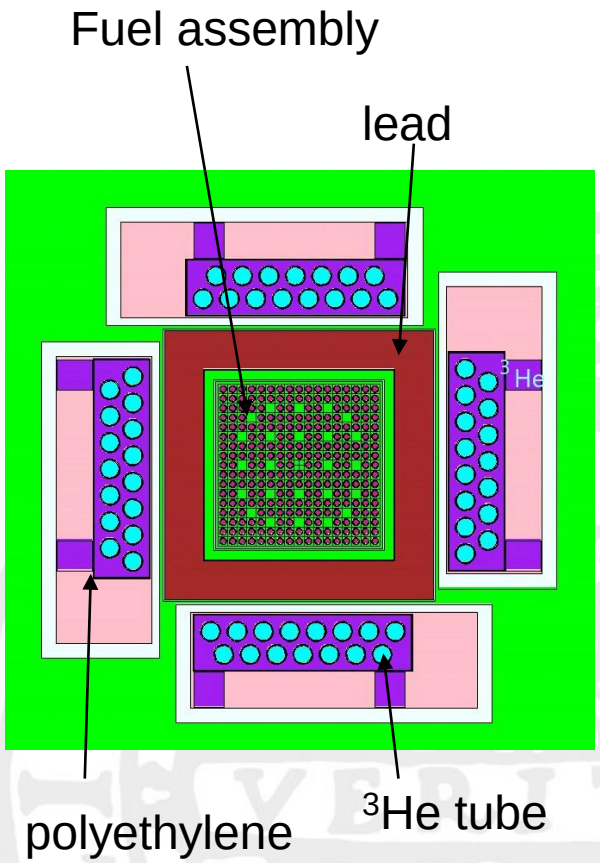
- MVA methods allow combining different signatures

- Variables brought to normal form to be comparable
  - Relative activity of ^{137}Cs and ^{154}Eu
  - Neutron signal from DDSI intrument

Differential die-away self-interrogation instrument

- Instrument developed and built in LANL
- 56 ^{3}He tubes detect thermal neutrons
- List-mode operation
- Rossi-alpha distribution (RAD)
- Measure **early die-away time**

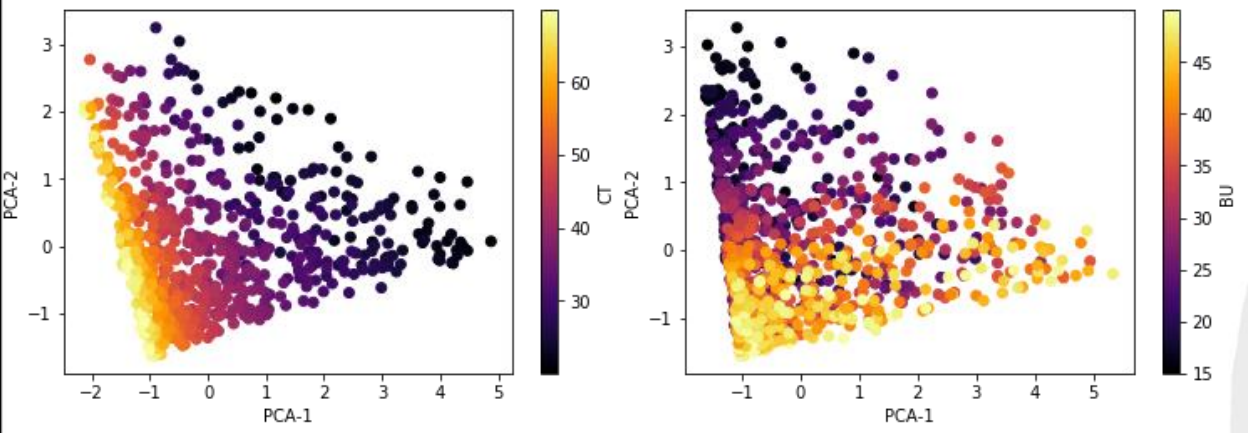




Visualize with: Principal component analysis

- Same data, colored with:

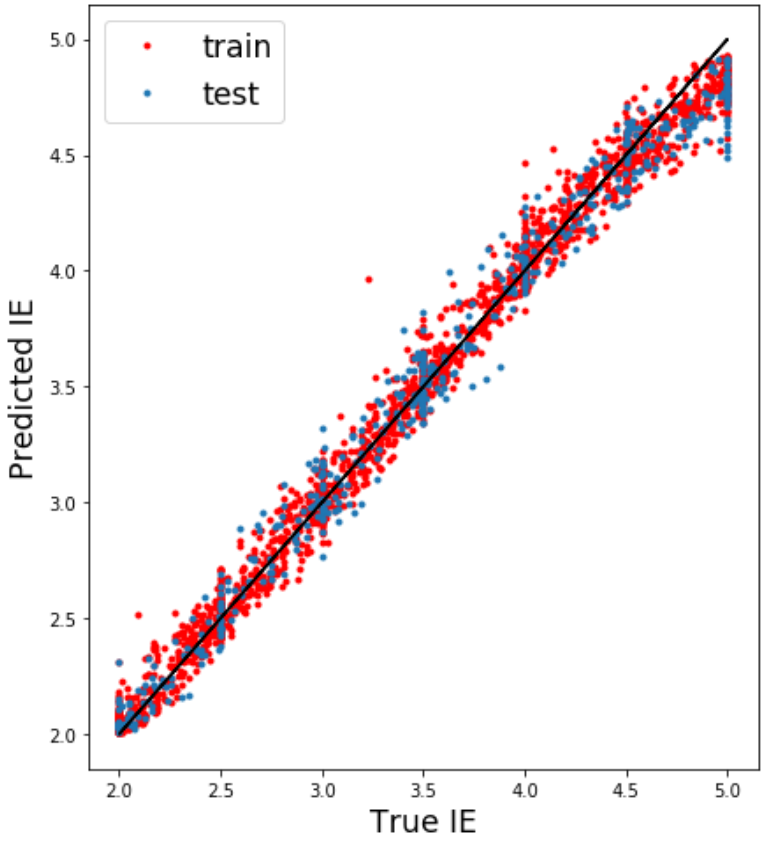
CT BU IE

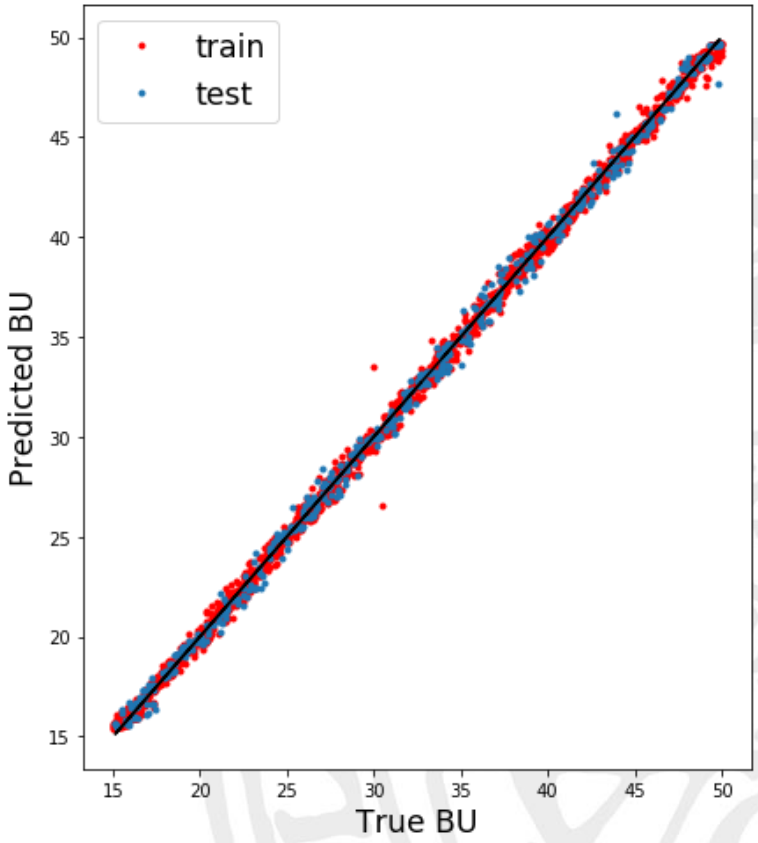


- CT trends with first component

If CT known: Random Forest regression

- Use true CT to correct the relative activities



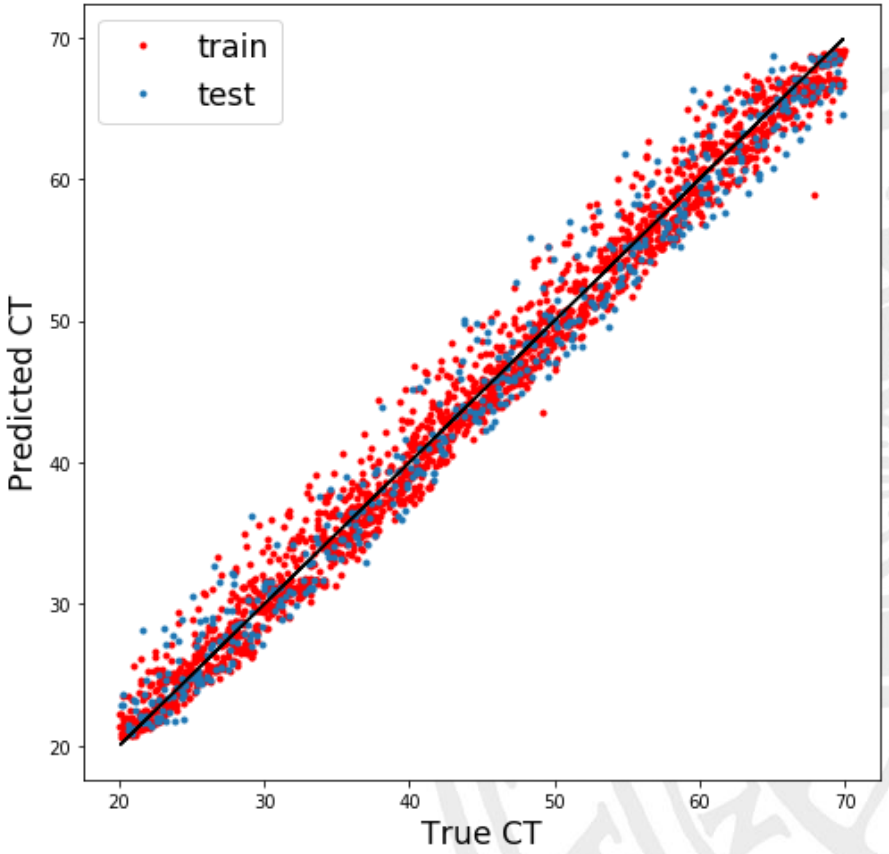


Root mean square error: 0.13% 0.5 GWd/tU

If CT unknown: Random Forest regression

- Determine CT with Random Forest regression

Root mean square error:
2.3 y
(1.8 y for train)



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SUMMARY AND OUTLOOK

Summary & Outlook

- Multivariate analysis versatile tool
- Passive neutron and gamma measurements to characterize spent fuel
  - Regression with good results up to 70 years CT
  - Try other algorithms (f.ex. PLS in previous article)
  - Include other signals?
  - Experimental validation with data from Clab

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Thank you for your attention!

Questions?

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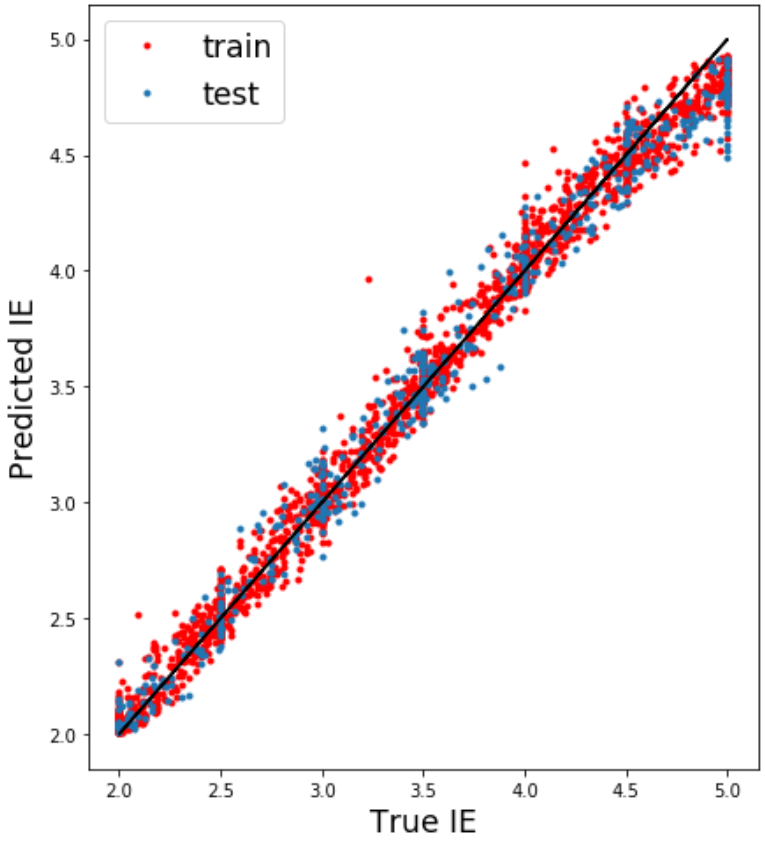
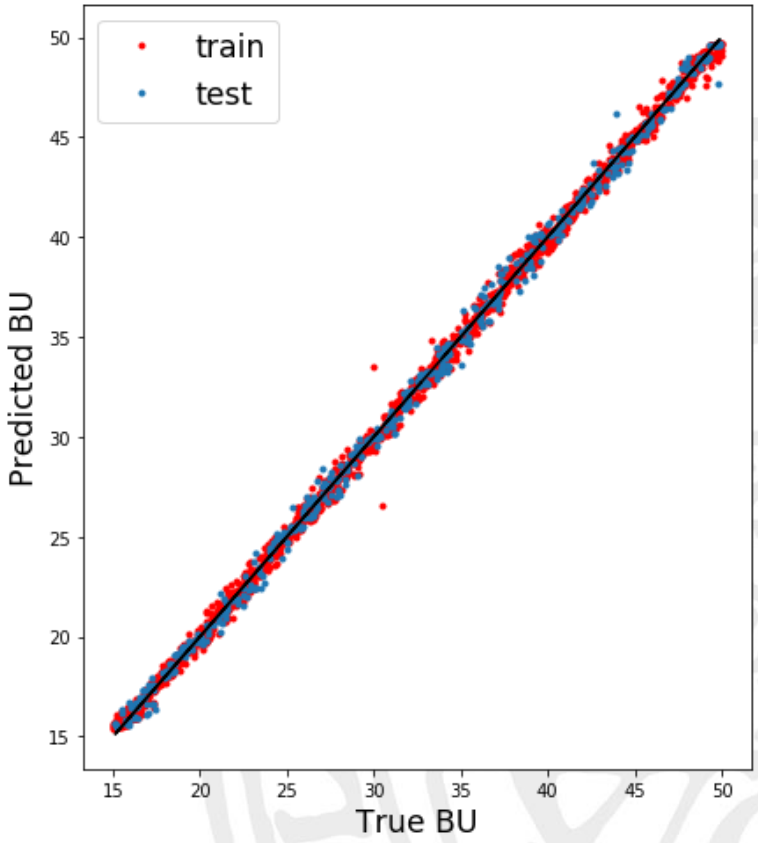
BACKUP

If CT known: Random Forest regression

- Use true CT to correct the relative activities





Root mean square error: 0.13% (train 0.10%) 0.5 GWd/tU (train 0.4)