Real-time fast neutron plutonium assay for plutonium storage and ageing applications

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The project

- **Objective:**
  1. Can plutonium (^{240}Pu) be discerned from Curium (^{244}Cm) in the field on the basis of differences in their fast neutron fission multiplicity distributions?
  2. Can the relative difference between uncorrelated, 'singles' neutrons derived from Americium (^{241}Am) and correlated neutron emissions from Plutonium (^{240}Pu) be exploited to infer plutonium ageing?
- **Motivation:**
  1. Small quantity of Curium in waste assay can result in severe over-estimation of plutonium and under-estimation of uranium content as well as large uncertainties
  2. can act as intense neutron source, masking signal from Pu-240

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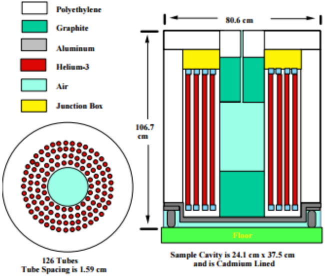
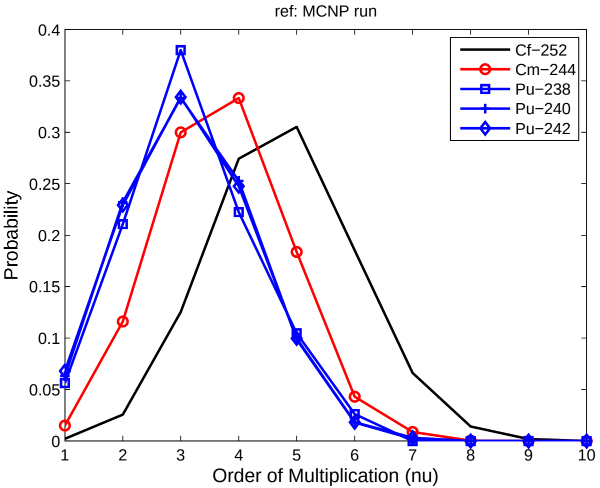
Possible Solutions

- Gamma Spectroscopy
- Simulations and laboratory analysis
- Multiplicity Analysis



Multiplicity



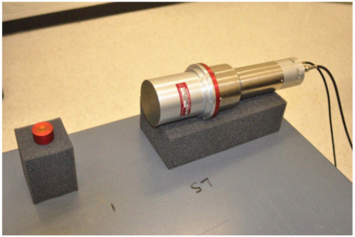
Multiplicity: Neutron Detectors

Helium-3 Detectors

- increasingly rare commodity
- requires thermalization
- long detection gate
- cannot discriminate between neutrons from different isotopes

Liquid Scintillation Detectors

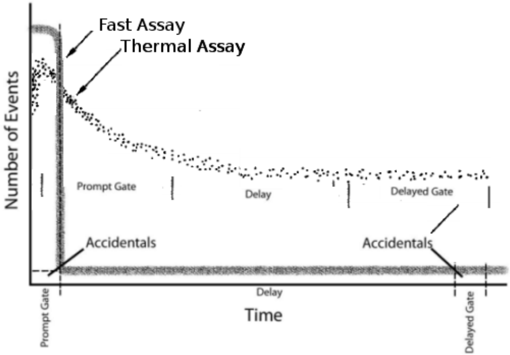
- does not require thermalization
- very short detection gate
- sensitive to both gamma and neutron radiation



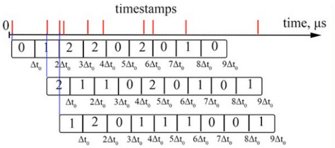
Multiplicity: Data Analysis Methods

- Rossi-alpha Method
- Feynman-alpha Method

Multiplicity: Rossi-alpha Method

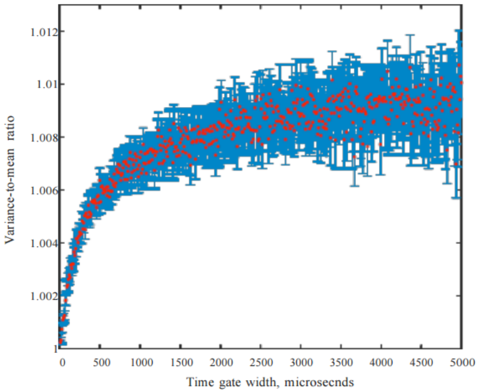


$$P(t) = Aexp^{-\alpha t} + F\epsilon$$

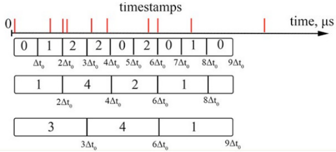


REFERENCES:
1 N.Ensslin, "Passive nondestructive assay of nuclear materials," (Los Alamos National Laboratory, Los Alamos, NM 87545, 1991) Chapter 16, pp. 457-488, 2nd ed.
2 M. J. Joyce, J. Adamczyk, M. D. Aspinall, F. D. Cave, , and R. Plenteda, "Real-time, fast neutron detection for stimulated safeguards assay," in Proceeding of the 37th ESARDA symposium on Safeguards and Nuclear Non-Proliferation (2015).

Multiplicity: Feynman-Y Method



$$Y_{\text{var}}(iT) = \frac{\nu(iT) - \mu(iT)}{\mu(iT)}$$



Statistical method: Neutron counts with respect to various counting gate widths are measured to obtain the gate width dependence of the variance-to-mean ratio of neutron counts minus unity.

REFERENCES:

1 D. Chernikova, Syed F. Naeem, Nermin Trnjanin, KÃĕre Axell, Anders Nordlund, "Gamma Rossi-alpha, Feynman-alpha and Gamma Differential Die-Away concepts as a potential alternative/complement to the traditional thermal neutron based analysis in Safeguards,"

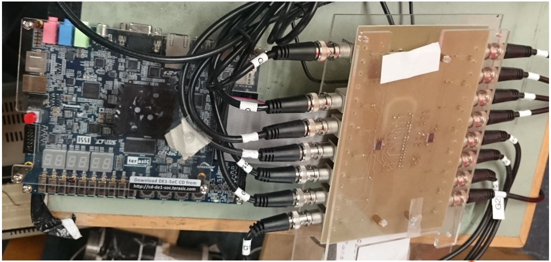
Progress

- Number density analysis - paper drafter and under review
- Simulating neutron cross talks in MCNP- two papers proposed
- Simulating multiplicity and light responses from liquid scintillator in MCNP and Geant4 - MCNP completed, progess being made on Geant4
- FPGA-based real time system capable of carrying out online data processing - success achieved, one paper drafted

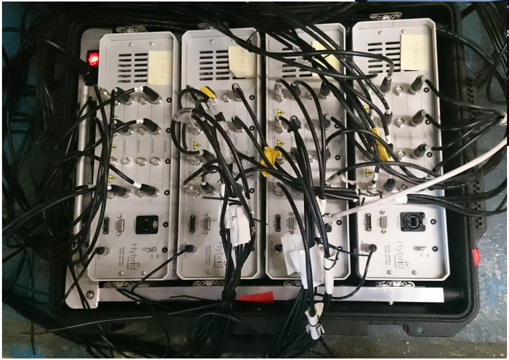
Hardware: Multiplicity register

Based on Altera DE1-SoC FPGAs

- Runs linux kernel, to allow user to connect monitor and keyboard to use device as a standalone system.
- Rossi-α & Feynman-Y using shared circuit
- Time-of-flight analysis

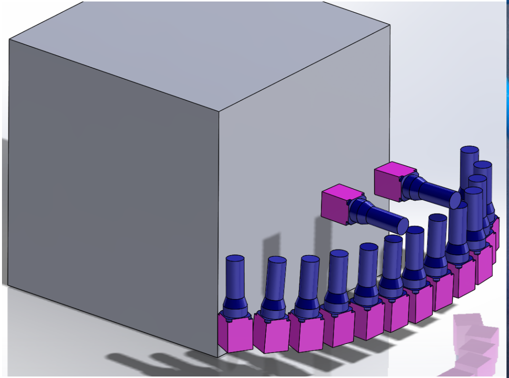


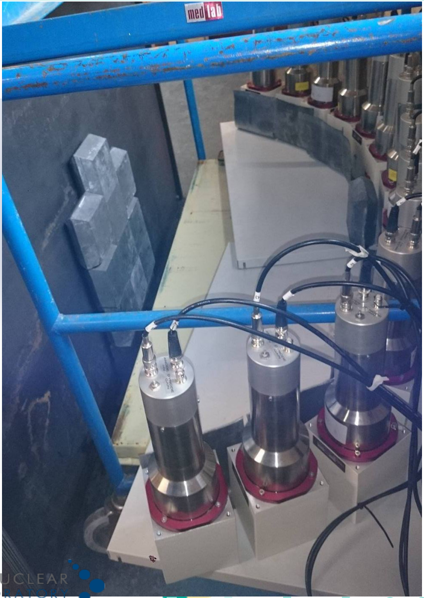
Hardware Interlink



Hardware Results: Experimental setup

Exp1: Source exposed
Exp2: Source stored
Neutron: Neutron coincidence only
Joint: Both neutron and gamma coincidence



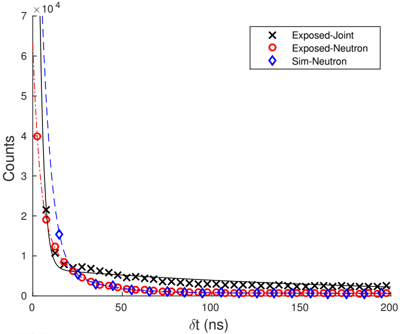


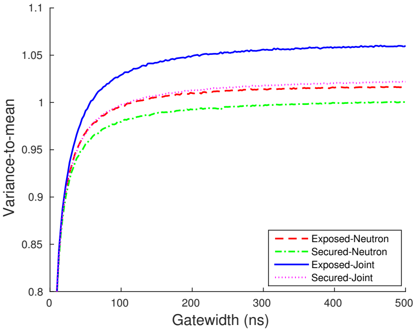
Hardware Results: Rossi-alpha & Feynbman-Y distribution

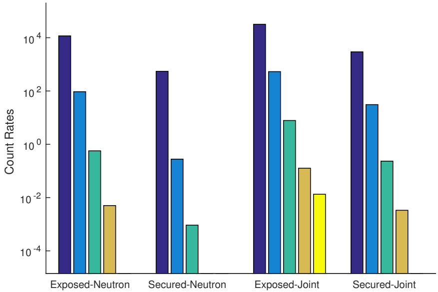
Neutron: Neutron only; **Joint**: Both neutron and gamma;

- similarities in the trends between sim and exp
- sim can't take into account detector deadtime
- artifact in the joint signal, indicative of neutrons-gamma velocity relation

- Amplitude can determine multiplication
- Secured-Neutron has the lowest multiplication
- Exposed-Joint is the highest due to combined effect of gamma-neutron multiplicity







Neutron: Neutron coincidence only
Joint: Both neutron and gamma coincidence

- amplitude can determine multiplication
- Exp2-Neutron has the lowest multiplication
- Exp1-Joint has the highest due to combined effect of gamma-neutron multiplicity

Future work

Planned work

- Unfolding multiplicity distribution
- Controlled cross-talk based experiments
- Am-241Be/Cf-252/Cm-244/Pu-240 based multiplicity experiments
- Semi-empirical model for neutron cross-talk
- Designing of detection system
- Neutron multiplicity as a function of neutron energy
- Neutron-Gamma joint multiplicity.

Thank you!