WG6 IPNDV Experimental Technology Data Sheet

January 20, 2020, G. Bentoumi/L. Li, Canada

Name of Experimental Campaign:
Belgium exercise to investigate performance of measurement methods

Technology Name: Passive Neutron and Gamma-ray Techniques for Special Nuclear Material (SNM) Detection

Physical Principle/Methodology of Technology:
For the SCK●CEN demonstration in Belgium, Canadian Nuclear Laboratories (CNL) proposed and used passive neutron and gamma-ray techniques to probe objects for presence of fissionable materials (FM), including special nuclear material (SNM), and identify relevant signatures. Passive counting techniques seek to detect FM by counting gamma rays and spontaneous fission neutrons if emitted from the resident sample. Most FM isotopes exhibit a low rate of spontaneous fission neutron emission. For example, the spontaneous fission neutron yields from ^{235}U and ^{238}U are 2.99×10^{-4} $n \cdot s^{-1} \cdot g^{-1}$ and 1.36×10^{-2} $n \cdot s^{-1} \cdot g^{-1}$ respectively[1]. This low spontaneous fission yield combined with self-absorption of prompt neutrons and low detection efficiency of typical counting systems lead to weak and statistically poor response signals relative to background. Passive counting methods could reveal possible existence of FM by examining the neutron counting rate, and/or the Rossi-Alpha spectrum generated from neutron counting in coincidence mode.

[1] N. Ensslin. “Chapter 11: The Origin of Neutron Radiation.” In D. Reilly, N. Ensslin, and H. Smith Jr. (Eds.), *Passive Nondestructive Assay of Nuclear Materials* (Washington, DC: Office of Nuclear Regulatory Research, U. S. Nuclear Regulatory Commission, 1991): 337–356.

What Does the Method Determine/Measure (e.g., presence of nuclear material, isotopics, mass):
The method determines the presence of nuclear material of interest. The main objective of these experiments was to assess the usefulness of a high detection efficiency neutron and gamma-ray counting systems. Tasks involved establishing technical capabilities in using passive neutron and gamma-ray counting techniques to probe objects for presence of FM and identify relevant signatures for nuclear disarmament and forensics purposes.

What Is the Applicability to IPNDV:
The task aimed to explore novel analytical techniques based on spontaneous fission analysis and mid-resolution gamma-ray spectral analysis for application in nuclear disarmament and forensics. The ability to verify the presence/absence of nuclear material, and characteristics such as chemical and isotopic compositions, originating from a nuclear weapon was tested.

Type of Data Collected by the Technology:

- Gross neutron count rate;
- Gamma energy spectrum;
- Rossi-Alpha distribution (coincidence measurements).

Constraints (e.g., time to install the equipment, measurement times including distance from object, dose rate required, required Cd shielding to limit the count rate):

- Samples were not representative of nuclear warheads in terms of shape and neutron/gamma emission rates or dose;
- Samples were too hot for gamma measurements (needed to use a collimator);
- Measurement times were too short; one day for all samples was not sufficient.

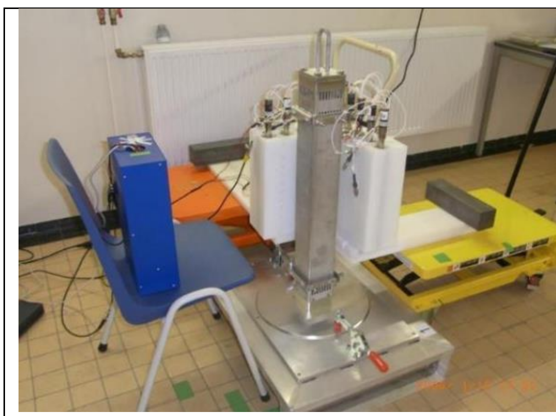
Physical Description/Diagram/Photos of the Experimental Setup/Layout:

Neutron Techniques: ***<u>Gross Counting and Coincidence Modes</u>***

The neutron counting system (NCS) system consists of several He-3 thermal neutron detectors that are interspersed throughout a polyethylene moderator. The system is adjustable and can be positioned on a platform to accommodate any size and shape of sample. Neutrons are counted using an MCA-527 multi-channel analyser from GBS Elektronik, which is capable of measuring count rate and also creating a Rossi-Alpha spectrum in real time.

Gamma-rays Techniques: ***<u>Gross Counting and Spectroscopic Modes</u>***

For the gamma-ray measurements, two commercial mid-resolution gamma spectrometer detectors were used: one based on NaI, and the other on CLYC crystals.



Specific Objects Measured (which of the experimental objects were measured; if not described elsewhere, describe experimental objects here):

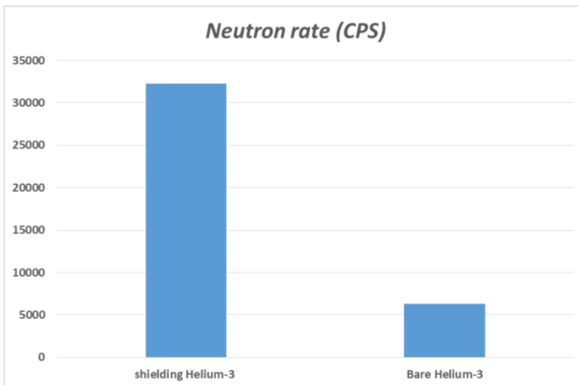
The table below lists the specific objects measured along with the configuration of the measurement system.

^{239}Pu % (isotopic)	Number of Pins	Sample total mass (kg)	^{239}Pu mass (kg)	Configuration
62	**1**	0.5	<0.1	**1.** No shielding
62	**19**	10.2	0.8	**2.** No shielding
62	**61**	32.8	2.6	3. No shielding
				4. 5 mm Pb

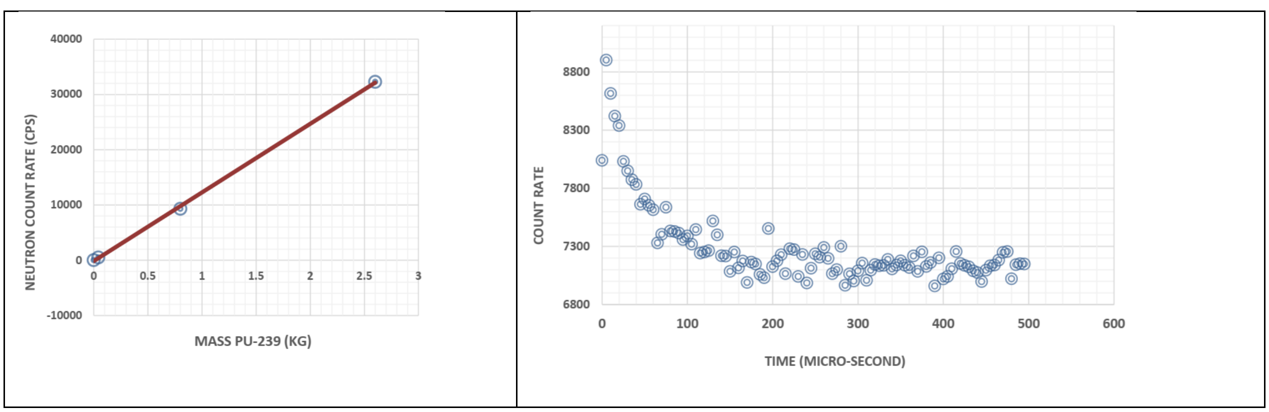
				5. 50 mm polyethylene (CH2) 6. 50 mm CH2 + 10 mm Pb 7. Cd shielding; He3 inside HDPE 8. Cd shielding; He3 outside HDPE 9. No Shielding; He3 outside HDPE
79	**19**	6.2	0.2	10. No shielding
96	**19**	6.2	0.2	11. No shielding

Process Required to Analyze the Data (include any software used):
Excel and Origin were used to process the data for visual analysis.

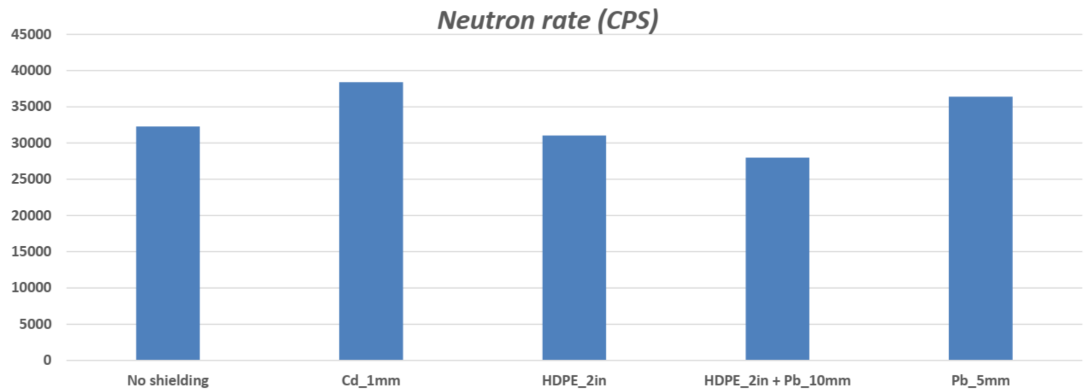
Preliminary Results (qualitative, not quantitative; e.g., did the method perform as expected, if not how was it different):



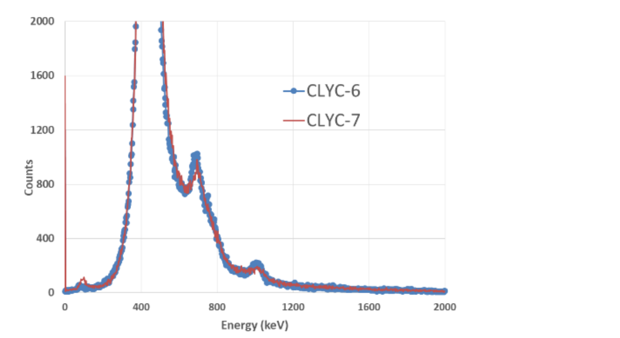
By comparing the neutron count rate for configurations with the He-3 detectors shielded and unshielded, one can qualitatively asses the neutron energy spectrum. For sample with 62% of ^{239}Pu, the count rate drops significantly when a bare He-3 detector is used, indicating the presence of fast neutrons.

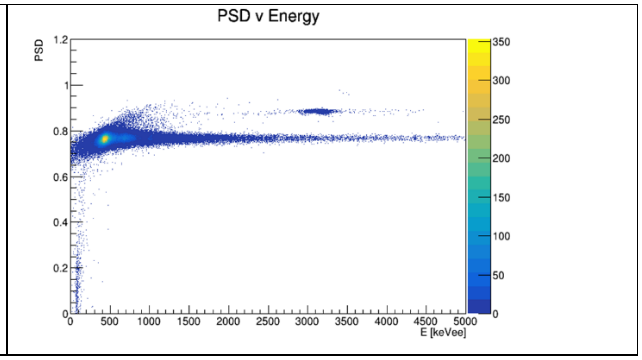


(Left) Shielded He-3 (fast neutrons) counting. (Right) Example of neutron coincidence and Rossi-Alpha distribution for configuration 3 with 62% of ^{239}Pu. Neutron count rates are linearly proportional to ^{239}Pu mass of the sample (left) and are confirmed to originate from a fission source by observing the typical Rossi-Alpha distribution (right).



Neutron count rate for different shielding configurations are shown above. Count rate is observed to increase when Pb or Cd shielding materials are used. We suspect this is due to gamma rays generated by interaction of fast neutrons with these shielding materials, which leads to pile-up providing signals above threshold.





Above are presented gamma ray spectrums for configuration 11 (sample with 96% of ^{239}Pu). Due to mid-resolution capability of the gamma detectors, results are combination of peaks originating from U and Pu isotopes as well as from ^{241}Am. System's resolution was not good enough, and therefore was not able to identify peaks due to Pu or U.

Final Results (if available; if not, estimate of when final results will be available):

- Able to detect nuclear material (NM) using both neutron and gamma techniques;
- The observed high neutron count rate eliminates U as main component of NM;
- Mid-resolution detectors were not able to confirm isotopic composition;
- Comparison with neutrons and gamma measurements at CNL suggests the samples contain significant portion of Pu.

Lesson Learned (e.g., what went well, what went wrong or not as expected, do the results confirm what we said in the technology tables?):

- The relatively intense gamma signal from ^{241}Am is strong making mid-resolution gamma detectors (NaI and CLYC) non-useful for identification of plutonium and uranium. More analysis is required to use these detectors.
- Experiments should focus on one particular sample.
- Collimators may be required for gamma measurements depending on the sample.