WG6 IPNDV Experimental Technology Data Sheet

Version 1, 20191120, A. Borella, Belgium

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

Technology Name: Neutron Coincidence Counting

Physical Principle/Methodology of Technology:
The technology measures the time correlation between events measured with neutron detectors. Time correlated events are studied in two time windows to determine the so-called totals rate and reals rate, indicated with *T* and *R* respectively. With more sophisticated data acquisition systems, the multiplicity distributions of such events in the two time windows can be determined. *T* and *R* corresponds to the first and second moment of such distributions.

R is a measure of the amount of material emitting neutrons by spontaneous fission.

What Does the Method Determine/Measure (e.g., presence of nuclear material, isotopics, mass):
The totals and reals count rates (indicated with *T* and *R*) are measured. In the proposed approach we apply Hage's point model (NIM A 251 (1986) 550-563) to determine the intensity of the spontaneous fission (SF) source term and detection efficiency.

From the spontaneous fission source term by knowing the isotopic composition of the sample (e.g., from gamma-ray spectrometry) and it is possible to determine the 239Pu mass.

Additional information can be obtained if one is able to calculate other moments of the neutron multiplicity distributions in the two time windows, in addition to *T* and *R*.

What Is the Applicability to IPNDV:
Verification of NED material. How easily can weapon grade material be shielded. Limit of detection.

Type of Data Collected by the Technology:
Total neutron counts, correlated counts in two time windows ("R+A" and "A"), total measurement time. In addition, it is also possible to save the time stamps of detected events and from that determine the multiplicity distribution and moments of such a distribution.

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):
Each detector weighs about 50 kg so they are transportable but not portable.

Measurements were done at two distances, 26 cm and 95 cm, from the outer surface of the assembly.

The measurement time depends on the neutron emission of the sample and was either 1800 s or 3600 s. The uncertainty on the reals rate *R* was about 2% at 26 cm distance and about 5–10% at 96 cm.

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Physical Description/Diagram/Photos of the Experimental Setup/Layout:
Two WM3400 slab counters were deployed. The sample to be assayed is between the detectors.

Totals, "R+A," and "A" measured with a JSR-12 shift register. Each detector is equipped with a shift register. The logical "OR" of the signals is also processed by a shift register as well as an MCA527 from GBS-Elektronik with upgraded firmware. The upgraded firmware allows saving the time stamps of the detected event for an offline analysis to determine the distribution of correlated events.

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Specific Objects Measured (which of the experimental objects were measured; if not described elsewhere, describe experimental objects here):
Fuel with composition as specified in "Design information IPNDV_v03.pdf."

Mechanical design of the fuel container as given in "105761 - Measurement setup IPNDV.zip."

The fuel type is indicated as follows:

- 96—50 cm fuel pins, dismountable, U_{enr} 0.72%, Pu content 4.37%, ^{239}Pu 96%
- 79—50 cm fuel pins, pelleted, U_{enr} 0.72%, Pu content 5.1%, ^{239}Pu 79%
- 62 H-MOX—100 cm fuel pins, H-MOX, U_{enr} 0.4%, Pu content 12.6%, ^{239}Pu 62%

The 62 H-MOX was measured in 1, 19, and 61 pins arrangements.

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All measurements were carried out with 1.1 mm Cd around the fuel assembly. For fuel types 79 and 96, the measurements were also carried out without Cd.

The fuel type 96 was also measured with 5 cm CH2 around the assembly and 1.1 mm thick Cd sheet on the detector and 5 mm Pb around the assembly and 1.1 mm thick Cd sheet on the detector.

Process Required to Analyze the Data (include any software used):
Determination of the totals and reals rate, then processing the data in excel to account for the gate factor and apply the Hage's point model equation.

Knowledge of the die-away of the system, measured with a 252Cf source (55.3±1.0 μs).

Preliminary Results (qualitative, not quantitative; e.g., did the method perform as expected, if not how was it different):
The data analysis reported here considers only the combined (via OR logic) response of the two slab counters. By considering the two detectors as a whole one limits the impact of possible asymmetrical detector arrangements.

Qualitative Comments
For the 96 case, closer to NED type, both totals and reals were insensitive to Cd, and almost insensitive to Cd+Pb (5% reduction on the totals), with CH2+Cd the totals were attenuated by 30% and the reals by 43%.

In all the cases the uncorrelated background was relatively high with the ratio A/(R+A) ranging from 88.4% (96+PE+Cd) to 99.8% (62 H-MOX, 61 pins + Cd, at 1 m distance). In the worst case, the reals rate could be determined with a relative uncertainty of 8%.

Results with Hage's Point Model
The Hage's point model equations (HPME) in absence of multiplication

$$T = F_S \nu_{s1} \varepsilon (1 + \alpha)$$
$$R = F_S \nu_{s2} \varepsilon^2$$

are solved by using *T* and *R* observables. In the equations, ε is the detection efficiency, α is the ratio between the neutron emission due to (α,n) reaction and spontaneous fission, F_S the number of fission per seconds, ν_{s1} and ν_{s2} are the first and second factorial moment of the distribution for the neutron emission through spontaneous fission.

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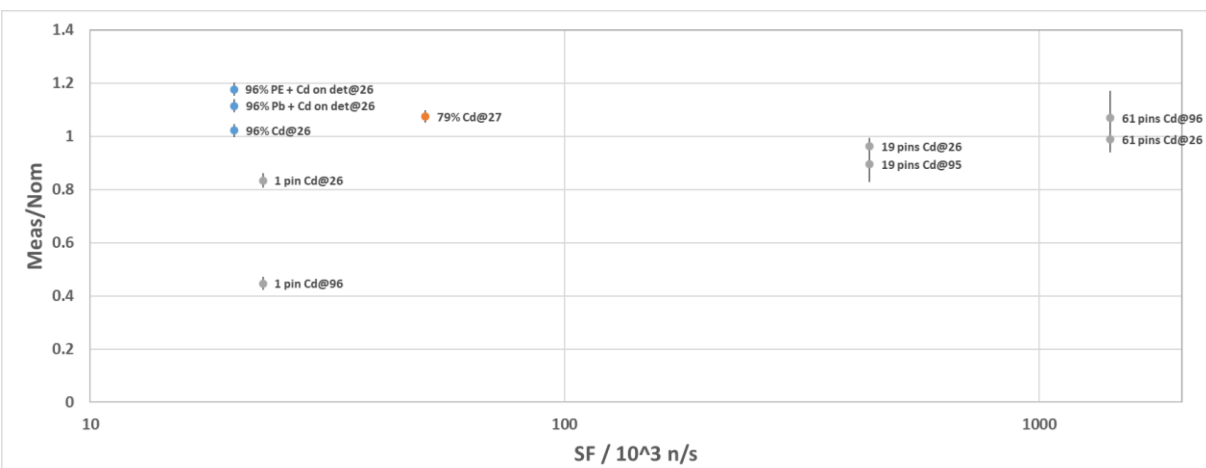
In the first results, the α term in the *HPME* is supposed to be known from the characteristics of the fuel. The first and second factorial moment (ν_{s1} and ν_{s2}) of the distribution for the neutron emission through 240Pu spontaneous fission were used in the data analysis. The contribution of F_S due to 238U is at least two orders of magnitude lower than the one of Pu and we assumed that F_S source term was only due to Pu when then extracting the 239Pu content by using the isotopic composition.

The obtained ratio between the calculated F_S source term and the nominal source term from the fuel specification for different cases and as a function of the nominal source term is shown below.

From the F_S, the 240Pu equivalent was calculated by assuming that the F_S was originating only from Pu.

By using the results of FRAM with the LEGE detectors (see other Experimental Technology Data Sheet), the 239Pu content was inferred. The obtained results compared with the nominal values are shown below.

The results for the 96 fuel are not given in these preliminary results. This type fuel is axially heterogeneous and the knowledge of the axial profile of the isotopic composition is needed to determine how to obtain the 239Pu content from the 240Pu equivalent.



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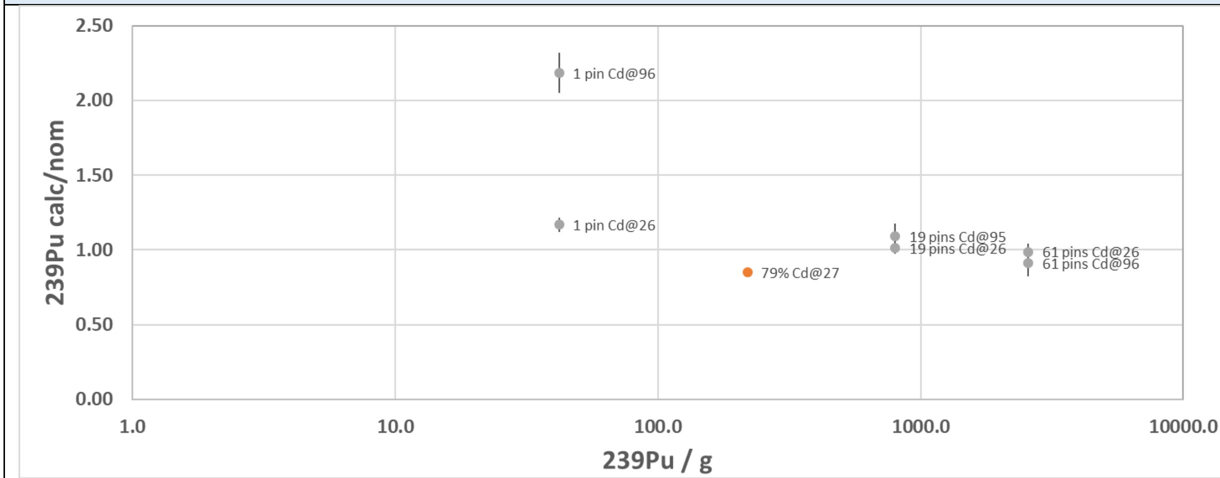

Relatively good results are obtained throughout the assemblies with the exception of the 1 pin case with 62 H-MOX fuel. This is probably due to the impact of a scattered radiation in the *T* term, which increases as the distance sample-detector increases.
Future work will include:

- Impact of dead time (~ 1 μs);
- Impact of multiplication factor;
- Impact of scattered radiation;
- Use of Monte Carlo (MC) simulations as to improve the accuracy of the results (e.g., to study the expected efficiency);
- Use of higher orders (triples) of the multiplicity distribution in the data analysis.

Final Results (if available; if not, estimate of when final results will be available):
It is foreseen to have final results in 2020–21.

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 measurements should have been as close as possible or in a closed geometry as to limit the impact of scattered radiation to the *T* term and increase the efficiency to be able to determine higher moments of the multiplicity distributions (e.g., the so-called triples). This is to be confirmed with MC simulations.