Contribution ID: **563** Type: **Paper**

Sensitive detection of special nuclear materials based on gamma-fast neutron coincidence counting for RPM application

The detection of special nuclear materials (SNM) is one of the main goals of the nuclear security chain, and Radiation Portal Monitors (RPMs) are extensively used to achieve this goal. These systems are designed to compare the measured neutron and gamma-ray counting rates with a predefined counting level when objects and/or persons passing through them, and set an alarm if the radiation rates are above a predefined level. The alarm level needs to be related to the normal background radiation and how background events may trigger false alarms due to statistical fluctuations is a critical point for the design of RPM systems. The higher the specificity of the sensor signals used for determining the alarm criteria the higher will be the "signal-to-background"ratio and consequently the lower will be the resulting false positive rate. At the same time the sensor efficiency must be high enough for optimum sensitivity.

The majority of RPMs designed to detect neutrons makes use of He-3 proportional counters or, to a lesser extent, organic scintillator detectors. Due to the global shortage of He-3 there is an increasing focus on He-3 free systems. Although both detector categories have proven to be efficient in detecting nuclear and radioactive materials, there are important issues related to "nuisance"alarms and difficulties in detecting small quantities of SNM, in particular in shielded environments, reported in the literature. A novel approach that addresses these issues utilizes the high multiplicity and short time-of-flight of gamma rays and their short time correlations with fast neutrons as a unique signature of materials that undergo spontaneous or induced fission, such as SNM. Making use of gamma-fast neutron coincidence counting as an additional detection modality in parallel with standard singles gamma and neutron counting the system sensitivity can be increased significantly, while neutron-neutron coincidence counting often is prohibitively inefficient. Efficient imaging of SNM materials within the field of view is also made possible using the gamma-fast neutron detection mode. Moreover, the use of coincidences adds to the system the capability of quantifying the material in question, expanding the applications from prevention of nuclear material trafficking to accountability and control.

Computational simulations are very useful and well accepted in the scientific community in order to investigate development setups and improve detection systems setups before mountain them. The theoretical accuracy in simulate nuclear fission, decay and radiation interaction with matter make Monte Carlo simulations codes a powerful tool in the area of nuclear security. This paper performed computational simulations to investigate the use of fast neutron and prompt gamma-ray coincidences detection in scintillators and the code MCNP (Monte Carlo N-Particle), version 6.2. was used. Spontaneous and induced fission including neutron, gamma-ray multiplicity and correlations were taken into account. Pulse Shape Discrimination (PSD) is the method applied to distinguish between neutron and photon pulses in the scintillator detector signal. In the computational environment the scattering of photons and neutron coming from the same fission event were counted as coincidences, when found inside different detectors in a pre-defined time window were counted as coincidences. The RPM prototype was modelled as double sided with two detectors assemblies containing four scintillator detectors each. The standard ANSI N42.35-2016 was used to define the RPM design and the source positions to perform the simulation. Count rates for single gammas, single neutrons, neutron-neutron and gamma-neutron coincidences were calculated and compared for the standard Cf-252 source and PuO2 samples in bare and shielded conditions. The detection zone was determined and a 3D map of counting rates percentage constructed. A discussion addressing the positive alarm threshold definition - as function of sigma and its multiplier factor - including particle miss-classification related to PSD in scintillators detectors is also presented.

The results showed high single-neutron and gamma-fast neutron coincidence rates. The latter was calculated being at least 10 times higher than the neutron-neutron coincidence rate in the bare source condition. The sigma multiplier factor for gamma-neutron coincidences was found to be significantly higher than the one calculated for single-neutron detection and the difference in performance was further increased in the presence of high-density polyethylene (HDPE) shielding. The novel method of gamma-neutron coincidence detection provided reasonable detection rates in the investigated setup even for small samples of SNM of the order of a gram and short inspection times of a few seconds. It provides a clean signature for SNM, promising to enhance the performance of future RPM systems significantly above the current state-of-the-art. Experimental studies of the prototype system will also be reported.

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Track Classification: MORC: Preventing illicit trafficking of nuclear and radioactive material