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Experimental Testing and MCNP Modelling of Spectroscopic Radiation Portal Monitors to Detect Illicit Trafficking of Nuclear Material

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1. Background and Goal of the present work

Spectroscopic Radiation Portal Monitors (SRPM) are used at checkpoints in order to detect the presence of nuclear or radioactive material, the efficiency of the monitors is important when it comes to avoiding illicit trafficking

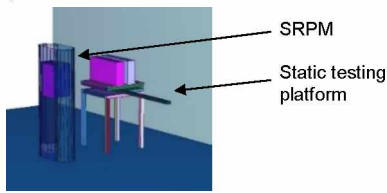
Simulations are used for the evaluation of the performance of SRPM in realistic conditions:

- Design substitute source of nuclear material when it is not available.
- Test scenarios, setups and operating characteristics of the Portal.

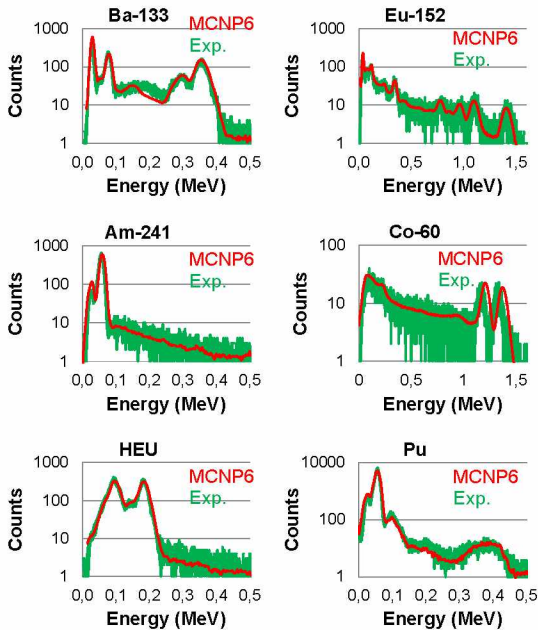
2. Portal and Sources Presentation

2.1. Portal and sources simulation

The SRPM model is based on the data of the user manual and certain simple assumptions. A comparison between empirical spectrum and MCNP6 simulated spectra of the NaI(Tl) detector is shown below.



MCNP model of the testing setup



Comparison between experimental and simulated pulse height distributions for 2s acquisition time.

The graphs show good agreement between simulated and measured energy spectra:

- For high-energy gamma rays the measured and calculated spectra match well,
- For low-energy gamma-rays a systematic difference and an under-estimation of the models are observed.

2.2. Alarm Threshold Calculation

The alarm threshold (AL) is a compromise between sensitivity and false alarms. AL can be expressed as a distance above the mean background (BKG) value in terms of M multiple of standard deviation:

$$AL = BKG + M\sqrt{BKG}$$

4. Conclusions

The code MCNP6 was used to calculate the detection efficiency of a SRPM. After a validation by experimental data, this model is used for:

- Making a substitute source for plutonium for experimental performance testing when nuclear materials are not available;
- Studying the performance of a SRPM in realistic conditions with different scenarios;
- Selecting the operating characteristics of the SRPM.

3. Simulation to help test Portals

3.1. Nuclear Material substitution to test (Pu example)

Test sources are used to check the performance of Portals. For Scintillator Detectors, with poor resolution, a combination of common gamma sources produces spectrum close to nuclear material. ^{241}Am and ^{133}Ba can be used as a substitute for plutonium for some detection testing.

Activities of substitution sources and tin shield thickness are optimized by simulation in order to fulfill as much as possible the equation:

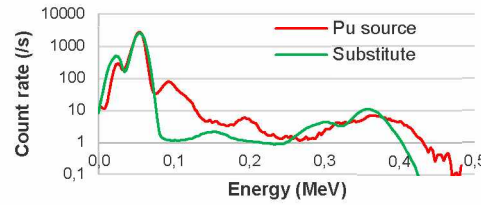
$$C_{Pu}(E) = Act_{Am-241} \times \epsilon_{Am-241}^y(E) + Act_{Ba-133} \times \epsilon_{Ba-133}^x(E)$$

Where:

- $C_{Pu}(E)$ is the count rate of the Pu source detected by the Portal at the energy E
- Act_{Am-241} , Act_{Ba-133} are the activities of the substitution sources
- $\epsilon_{Am-241}^x(E)$, $\epsilon_{Ba-133}^y(E)$ are the total detection efficiency of the substitution sources by the Portal at the energy E with x and y millimeters of tin shield wrapped around each source

Act_{Am-241} , Act_{Ba-133} , x and y are parameters optimized to minimize the sum of squared errors:

$$\min \sum_{i=0}^N (C_{Pu}(E_i) - Act_{Am-241} \times \epsilon_{Am-241}^y(E_i) - Act_{Ba-133} \times \epsilon_{Ba-133}^x(E_i))^2$$



Comparison between the real Pu source and the substitute

In the case of the tested Portal, the best substitute for 2 g of Pu is a bare source of ^{241}Am (1.55×10^7 Bq) combined with a ^{133}Ba source (1.08×10^5 Bq) wrapped by 2 mm of tin.

3.2. Performances testing by simulations (HEU example)

The counting uncertainty of the Portal counting σ must take into account all the variables inherent to the measurement:

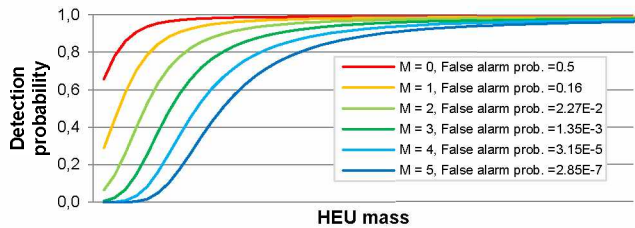
- Location uncertainty
- Background uncertainty
- Radiation absorption by metallic shield or self-absorption

Assuming that the counting distribution from a SRPM is a Gaussian distribution:

$$P_{Measure}(c) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left(-\frac{(\bar{c} - c)^2}{2\sigma^2}\right)$$

Where $\bar{c}(m)$ is the average count induced by m grams of HEU. The detection probability is the area from $P_{Measure}$ above the alarm threshold AL .

$$P_{Detection}(m) = \frac{1}{2} \times \left(1 - \text{erf}\left(\frac{AL - \bar{c}}{\sigma\sqrt{2}}\right)\right)$$



Detection probability between 30 keV - 300 keV with a bare source of HEU