An Introduction to the Delayed Neutron and Gamma Counting System at the Royal Military College of Canada

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Summary

The Delayed Neutron (DN) Counting System at the Royal Military College of Canada (RMCC) has been upgraded recentlywith the additional capability to record delayed gamma (DG) emissions from special nuclear materials (SNMs). This upgrade provided the opportunity to address several experimental deficiencies present in the system, including recombination and photon pulse pile-up effects in the ^{3}He detectors. These effects distorted the recorded temporal behaviour of DN emissions from SNM, which was detrimental when attempting to characterize fissile materials via the assessment of DN decay trends. The new capability to record both the DN and DG spectra as a function of time is described,and preliminary results are presented and discussed.

1. Introduction

The assay of delayed neutrons (DNs) produced from fissile materials is commonly used in the Canadian nuclear industry for the detection of failed CANDU® fuel [1] and more widely for the analysis of uranium content in geological samples [2]. Also, the technique of delayed neutron counting (DNC) lends itself to the fields of non-proliferation and nuclear forensic analysis [3]. Fissile isotopes and their relative quantities may be characterized non-destructively and rapidly, via the assessment of DNs. Each fissile isotope emits DNs with distinct temporal behaviour; a signature that can be used to identify special nuclear materials (SNMs).The purpose of the DNC system at RMCC has been to examine the DN emissions from fissile mixtures and determine the relative quantities of ^{233}U, ^{235}U and ^{239}Pu present in each sample.

Recently, the measurements obtained by this system have been compared to simulations produced by the monte-carlo code, MCNP6 [4], in collaboration with Los Alamos National Laboratory (LANL). The DNC apparatus at RMCC was upgraded recently to record simultaneously DNs and DGs from SNM. This upgrade provided an opportunity to address some of the previous system deficiencies, namely, recombination and pulse pile-up effects in the ^{3}He detectors.

2. A Description of the Original Delayed Neutron Counting System

Aqueous DNC samples containing fissile content were prepared from certified reference material and diluted by distilled water and nitric acid. These samples were encapsulated in 1.5 *ml* polyethylene (PE) vials before being sealed in a larger 7 *ml* vial. They were then sent via pneumatic

tubing to the SLOWPOKE-2 reactor at RMCC where they were exposed to athermal neutron flux ranging from 5.5 x $10^{11}$to $10^{12} cm^{-2}s^{-1}$fora 60*s* duration.Upon the expiration of this irradiation time, the samples were then sent to a DN counter, which consisted of an array of ^{3}He detectors (RS-P4-1613-202, GE Energy) embedded in paraffin wax, Figure 1. The pulses created in the ^{3}He gas within the detectors were recorded by LabVIEW^{TM} software and post processed by a Matlab^{TM} algorithm.Further details on the original system can be found in Reference 5 and thesimulation of irradiation and counting conditions in MCNP6 is detailed in Reference 6.

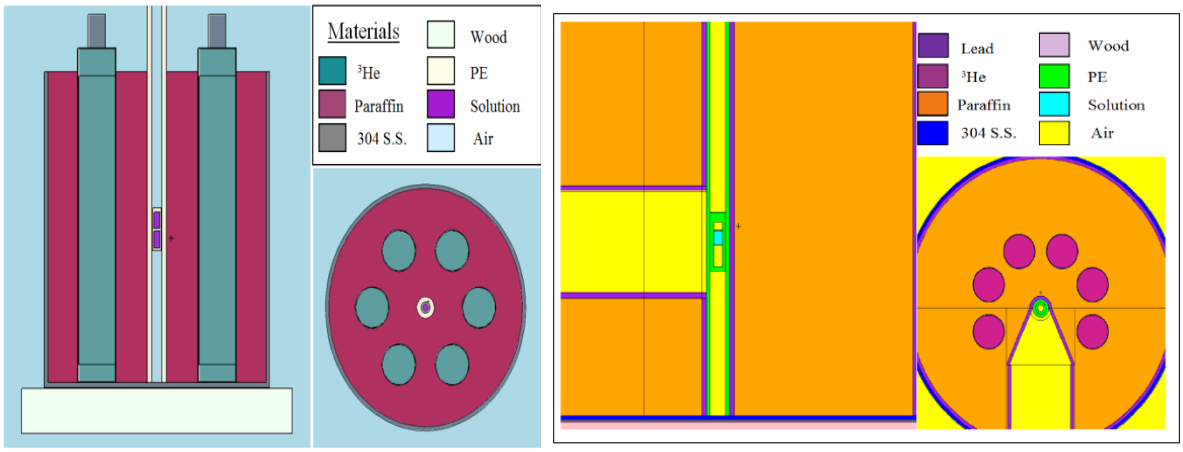

Figure 1 Original system detector arrangement (left) and the upgrade geometry (right).

The original neutron counting apparatus was a simple arrangement of all six detectors equidistant from the neutron source. PE tubing measuring 2.6 *cm* in diameter with a wall thickness of 0.45 *cm*surrounded the source vial. Neutrons were emitted from the vial and became thermalized through interactions in the PE tubing andthe paraffin moderator surrounding all six detectors . The ^{3}He detectors recordedcounts in time intervals as small as 0.5 *s* and a final ^{3}He energy spectrum at the end of neutron counting was recorded.

When a thermal neutron interacts with the ^{3}He gas within the detectors the following reaction occurs [7]:

$$ {}^{3}_{2}He + {}^{1}_{0}n \rightarrow {}^{3}_{1}H + {}^{1}_{0}H \qquad E_{total} = 0.764\ MeV $$

Some of the reaction products (^{3}H and ^{1}H) will come into contact with the walls of the detectors.Therefore, the detector will not record all of their kinetic energy; this is known as the wall effect and is evident in the spectra shown in Figure 2. Two further deviations from idealised behaviour occur. First, discrepancies at the lower energies (< 0.20 *MeV*) were found to arise from energetic γ-ray contributions. Multiple photons were recorded at the same time, resulting in a decrease in recorded counts, but an increase in the average energy deposited by these combined photons.

These γ-ray contributions were unfavourable as they distorted the temporal behaviour of the counts recorded by the system.When the pulse pile-up effects were severe, the energies of the recorded γ-rays began to approach the tail end of the neutron waveform (~0.20*MeV*) and were falsely interpreted by the system as neutrons. These contributions were reduced via energy discrimination; however this resulted in a decrease in system detection efficiency and in the case of very high γ-ray backgrounds, often associated with complex matrices, was not always effective.Also, γ-ray background increased the

system dead time effects, another distortion of recorded DN temporal behaviour. The second discrepancy between simulations and measurements, at energies ranging from 0.55-0.80*MeV*, arises from recombination effects. When there was an insufficient voltage applied to the detectors, some of the ion pairs produced wouldrecombine and not all of the energy was deposited. These two experimental deviations from MCNP6 simulations resulted in non-idealized energy deposition in the ^{3}He detectors.

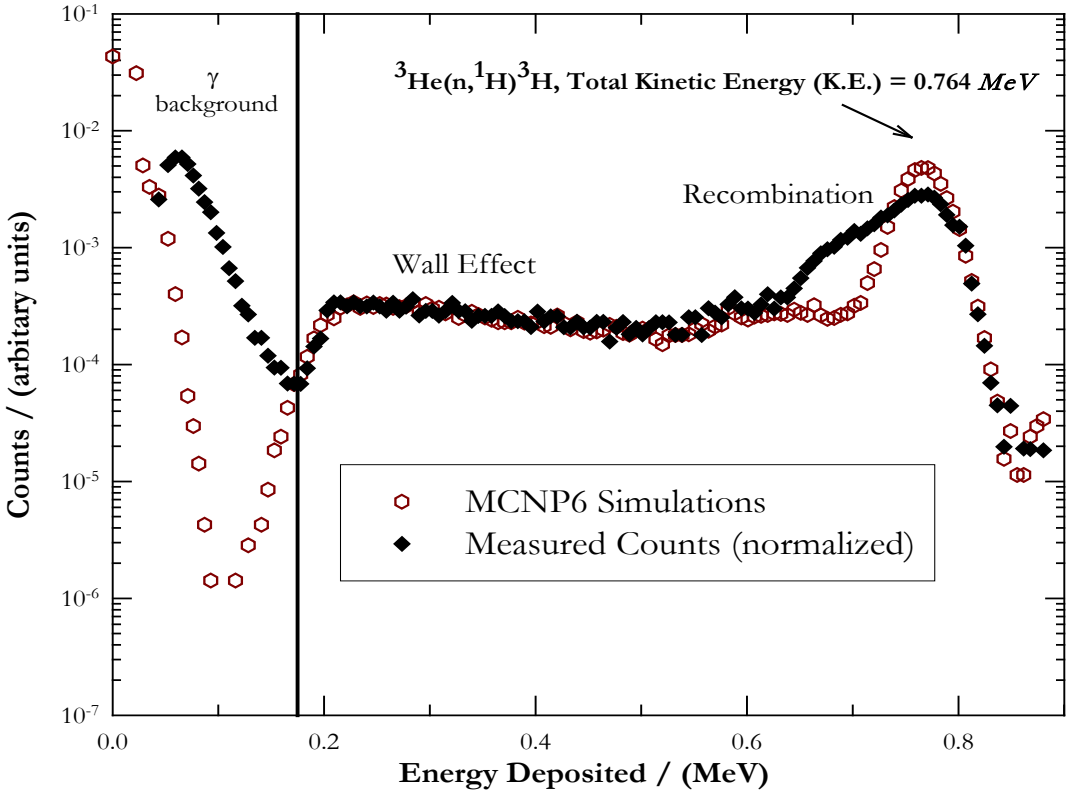

Figure 2 MCNP6 and Original Arrangement ^{3}He Spectra Comparison [8]

3. A Description of the System Upgrade

Arrangement 2 is part of a DNC system upgrade and is shown on the right of Figure 1. This detector arrangement is largely similar to its predecessor with three specific and notable differences. The capability to record gamma emissions through the use of a high purity germanium (HPGe) detector (GMX-1890, Ortec) has been included. The PE tubing that contains the source of neutrons is now surrounded by lead with a thickness of 0.5 *cm*to reduce the effects of γ-ray background within the^{3}He detectors (there is an opening in this lead shield to allow the γ-rays to penetrate the gamma detector).Software upgrades to the system allowed for the recording of the entire ^{3}He and HPGe detector energy spectra in 0.5 *s* count intervals rather than at the conclusion of counting duration.The sample analysis procedure is the same as with the previous set up, however the software now records the DGcounts and energies in addition to DNs.

4. Results

The changes in detector arrangement have had significant effects on shape of the recorded ^{3}He energy spectra, Figure 3.γ-raybackground was substantially reduced through the inclusion of lead shielding between the source and detectors, and is now negligible. The lack of photon background contributes to a lower dead time and reduced pulse pile-up effects. This is beneficial as it allows a more authentic determination of DN temporal behaviour when attempting to characterize mixtures of two or more fissile isotopes. Additionally, the system now has less severe recombination effects;as applied voltage to the detectors has been increasedfrom 1300 to 1500 *V*. Figure 3 illustrates the improved agreement between measurements and MCNP6 simulations .

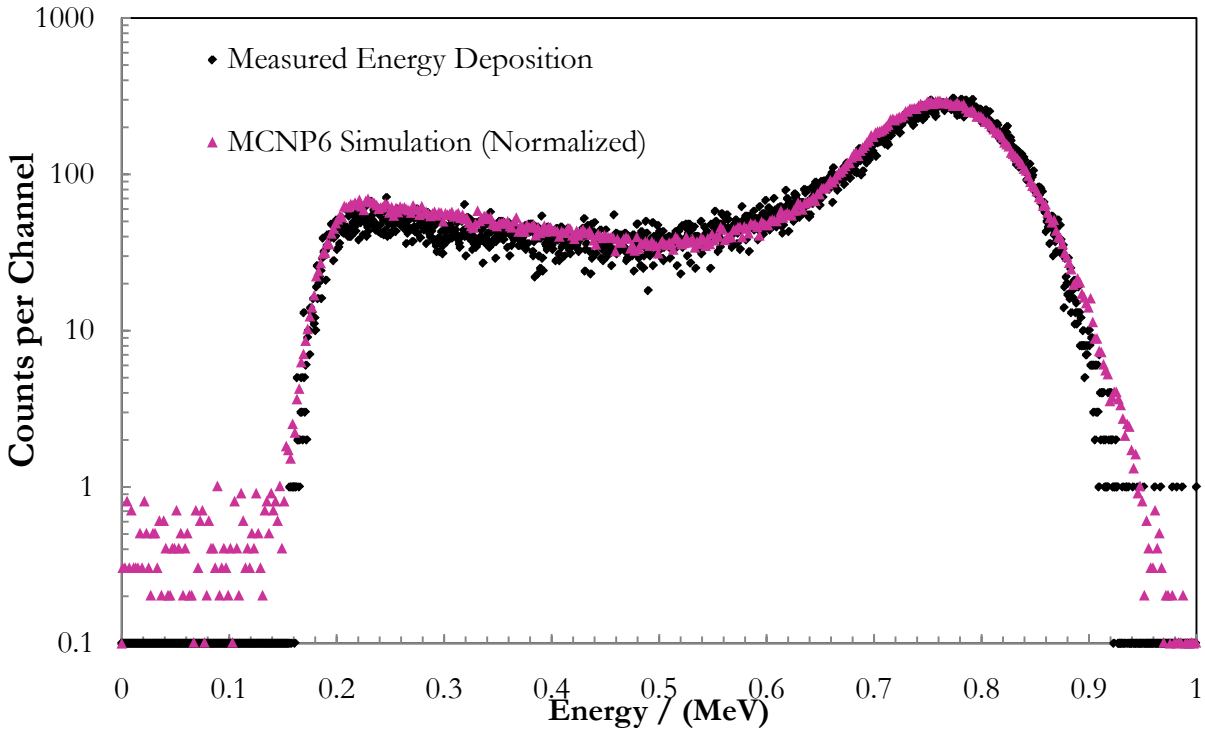

Figure 3 Upgrade Geometry and Improved ^{3}He Spectra

The new DG data collected by the upgraded system is displayed in Figure 4 . The LabVIEW™ platform has been modified so that the entire energy spectra recorded by the ^{3}He and HPGe detectors (16384 channels each) are recorded in predefined intervals (typically 2 *s* to 5 *min* in duration). This allows for the observation of individual γ-ray peak growth, which in turn can allow the identification of some fission products and their half-lives.

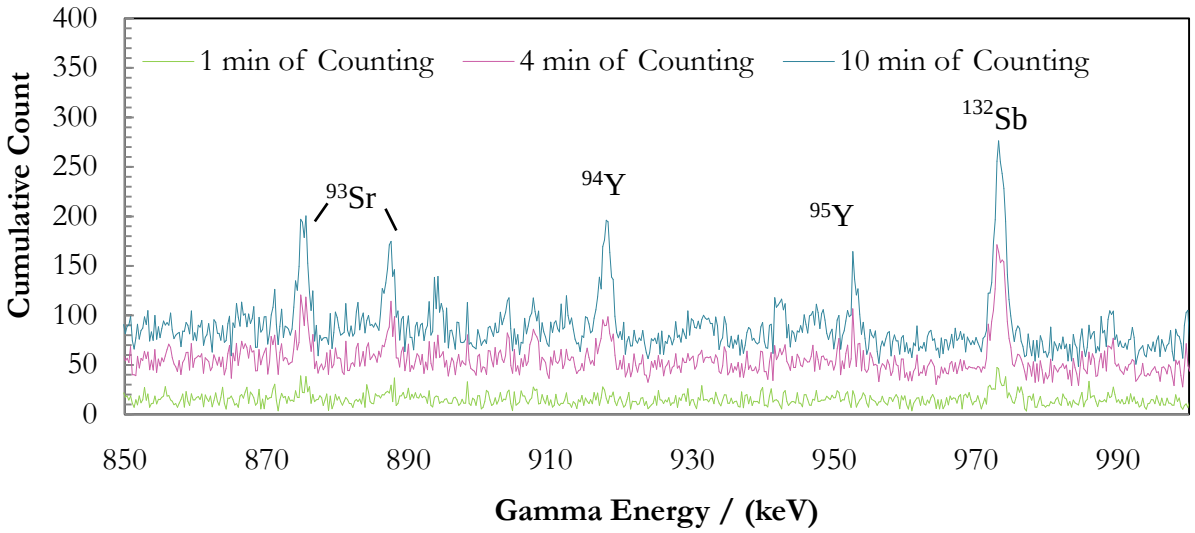

Figure 4 An example of recorded DGenergy spectra growth with time.

5. Conclusion

The upgrade of the DNC system at RMCC to include DG measurements from SNMs is well underway. Distortions to the recorded DN temporal behaviour were addressed and minimized through the elimination of γ-background and minimization of pulse pile-up effects.The ability to observe gamma energy spectra growth with time is now available.DN and DG recorded counts will both be compared to MCNP6 predictions in the future. The assay of the temporal behaviour of DN and DG from ^{233}U, ^{235}U, and ^{239}Pu will continue at RMCC with particular emphasis on nuclear forensic analysis and nonproliferation applications.

6. Acknowledgements

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7. References

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