MONTE CARLO EVALUATION OF THE USE OF A 14 MEV ASSOCIATED PARTICLE SEALED TUBE NEUTRON GENERATOR FOR ONE-SIDED MEASUREMENTS ON HIGHLY ENRICHED URANIUM SAMPLES

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ABSTRACT

In this paper, the Monte Carlo code MCNP-PoliMi was used to investigate the possibility of conducting active measurements on highly enriched uranium metal castings with an associated particle sealed tube neutron generator (APSTNG) as the interrogating source, and plastic scintillators as neutron and gamma ray detectors. The technique is based on the analysis of time-correlation functions of the signals from the source and the detectors to determine the mass and enrichment of the fissile samples. It is shown that the directionality of the APSTNG allows the measurement to be performed with the APSTNG and the detectors placed on the same side of the container.

INTRODUCTION

Nuclear Materials Identification System (NMIS) active measurements make use of an external interrogation source to induce fission inside the fissile sample under analysis [1]. Recently, efforts have been made towards the investigation of new sources for NMIS. In previous works, we reported on the advantages that a 14.1-MeV associated particle sealed-tube neutron generator (APSTNG) has over the traditionally used Cf-252 interrogation source [2]. One of the advantages is the possibility of performing measurements on fissile samples with the source and detector arranged on the same side of the sample. This capability is of great interest in the monitoring of fissile materials stored in container arrays, because the measurements could be simplified for arrays where the containers cannot be moved.

MCNP-POLIMI SIMULATIONS

A number of MCNP-PoliMi [3] simulations were performed to evaluate the possibility of performing one-sided measurements of uranium metal, in the form of castings. In the measurement configuration under analysis, an APSTNG source is placed on the same side as the detector, a plastic scintillator sensitive to fast neutrons and gamma rays. A tungsten block and a polyethylene block are used to shield the detector from the radiation from the APSTNG, as shown in Figure 1. The APSTNG detects a cone of alpha particles from the D-T reactions. Because the 14.1 MeV neutrons are emitted in the opposite direction from the alpha particle, a cone of neutrons is defined and aimed at the fissile material, as shown in Figure 1. The time of neutron emission is also registered by the alpha particle detector, and is used as the trigger pulse in the fast NMIS processor. The time dependent coincidence distribution of the pulses from the fast plastic scintillator with respect to the source pulse is measured.

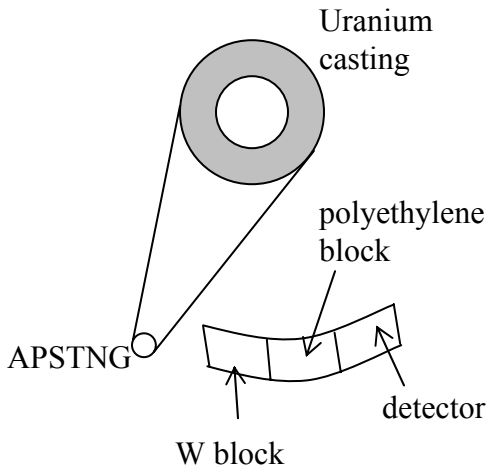

Figure 1. Sketch of the geometry of the MCNP-PoliMi simulations (not to scale).

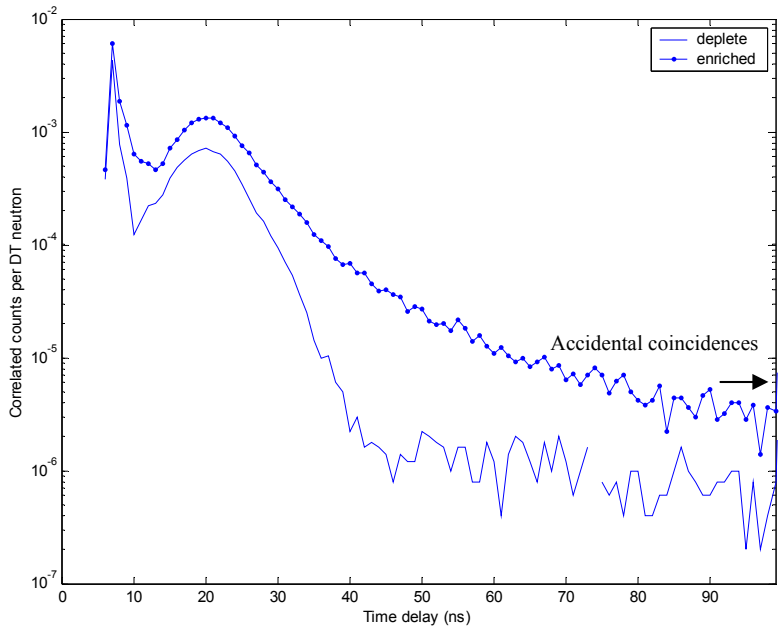

Figure 2. Source-detector cross-correlation for depleted and enriched uranium metal casting.

Figure 2 shows the simulated source-detector cross-correlation for a 93 and 0.2 wt% uranium metal casting, each having mass of approximately 18.5 kg. A feature of the post-processing code allows distinguishing the detections in the plastic scintillator on the basis of the particle type (neutron or photon) and their generation number. Generation zero particles are source particles, or particles generated in the interactions of source particles with nuclei by all interactions except for nuclear fission, whereas induced fission particles come from the first or following generations. Figures 3 through 5 show the signatures of Figure 2 subdivided according to these characteristics.

Inspection of these figures shows that the first peak of the cross-correlation, occurring at time lag 8 ns, approximately, is given primarily by photons. In the case of the enriched casting, it is shown that the photons come from fissions induced by the 14.1 MeV source neutrons, and by subsequent fissions. The second peak, occurring at time lag of approximately 22 ns, is given primarily by neutrons. In the case of the enriched casting, the second peak is given almost entirely by induced fission neutrons (Figure 3). In the case of the depleted casting, the induced fission neutrons are approximately a factor 2.5 greater than the generation zero neutrons (Figure 4).

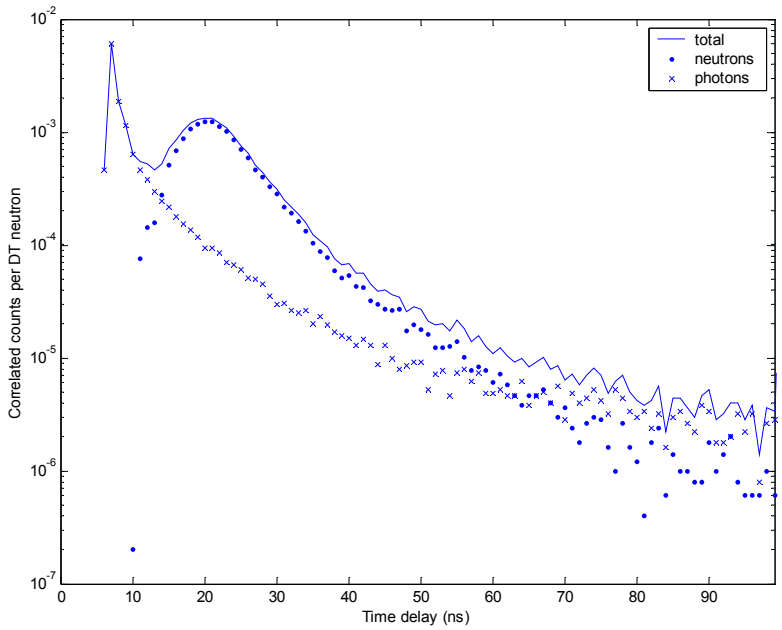

Figure 3. Source-detector cross-correlation for enriched uranium metal casting, subdivided into neutron and photon contributions.

Comparison of the total signatures given in Figure 2 shows that the neutron peak in the enriched casting is approximately a factor 2.5 greater than the corresponding peak for the

depleted casting. This feature, together with others that might be identified in the measured signatures, is sensitive to castings enrichment.

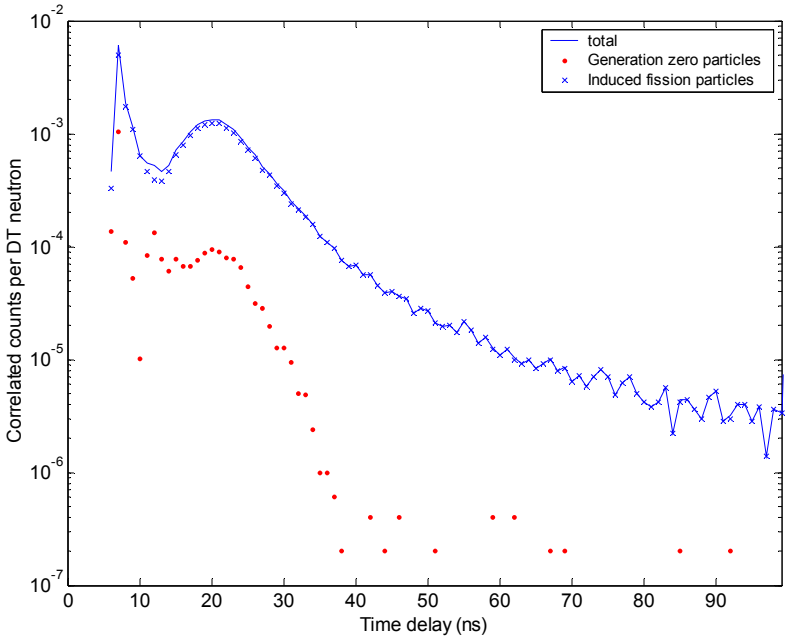

Figure 4. Source-detector cross-correlation for enriched uranium metal casting, subdivided into generation zero and induced fission contributions.

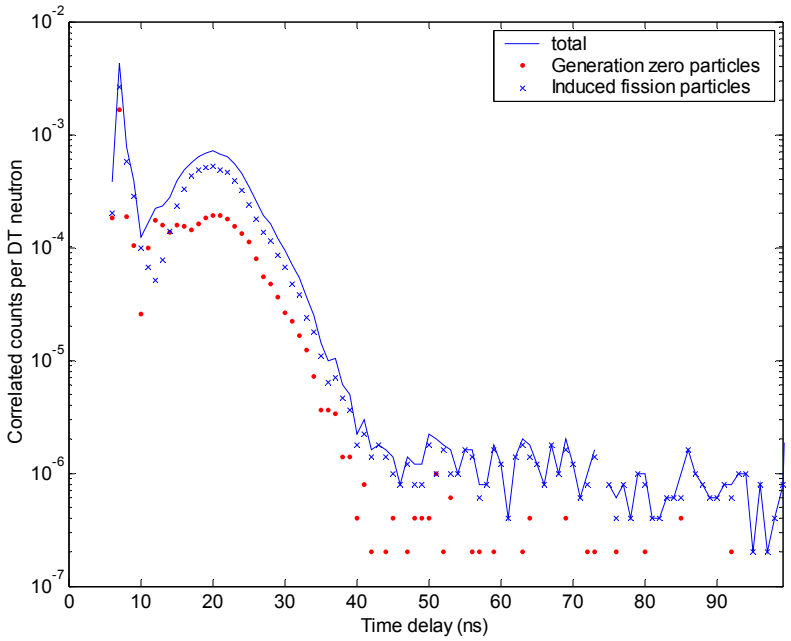

Figure 5. Source-detector cross-correlation for depleted uranium metal casting, subdivided into generation zero and induced fission contributions.

Table 1 shows the results of the tally of number of reactions occurring in the enriched and depleted castings for $50 \cdot 10^6$ source neutrons. The total number of induced fissions is approximately a factor 4 greater for the enriched casting compared to the depleted casting. The total number of (n, xn) reactions is greater for the depleted casting than for the enriched casting by a factor 2.5, approximately.

Table 1. Number of reactions occurring in the casting

Casting enrichment (wt%)	Source n	Induced fissions	(n, xn) reactions
93	$50\ 10^6$	$43\ 10^6$	$11\ 10^6$
0.2	$50\ 10^6$	$12\ 10^6$	$27\ 10^6$

The ENDF VI U-235 and U-238 cross sections for fission and (n,2n) reactions are shown in Figure 6.

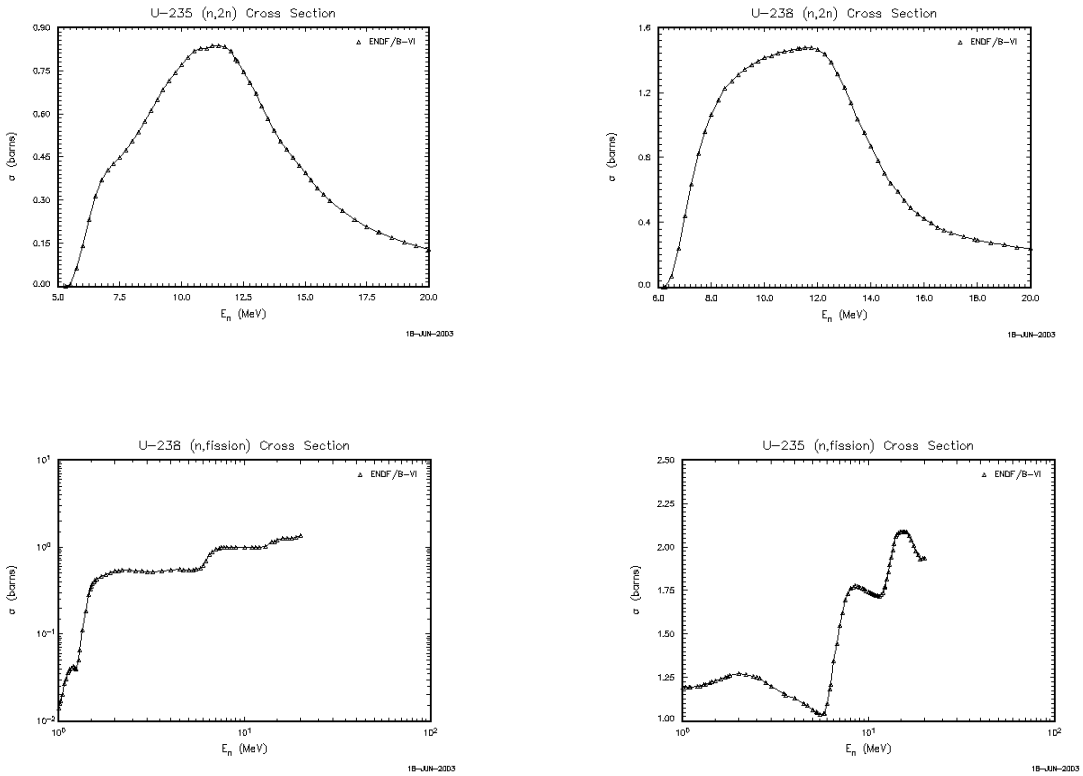

Figure 6. U-235 and U-238 cross sections for induced fission and (n,2n) reactions.

SIMULATION OF THE BACKGROUND COUNT RATE

A Monte Carlo simulation was performed to evaluate the total count rate that would be registered by the detector in the configuration shown in Figure 1. In the simulation, the APSTNG source was assumed to be isotropic. The simulation results are shown in Figure 7. The simulation showed that for 50 million source neutrons, approximately 35,000 detections were registered at the detector. If we consider the solid angle, and assume that the APSTNG has a yield of 10^7 n/s, then the measurement described in Section 1 would take 60 seconds, and the total count rate on the detector would be approximately 6000 counts per second. The background rate contributes to the accidental coincidences as indicated by the arrow in Figure 2, and is not significant. It is constant with time lag and can be easily subtracted.

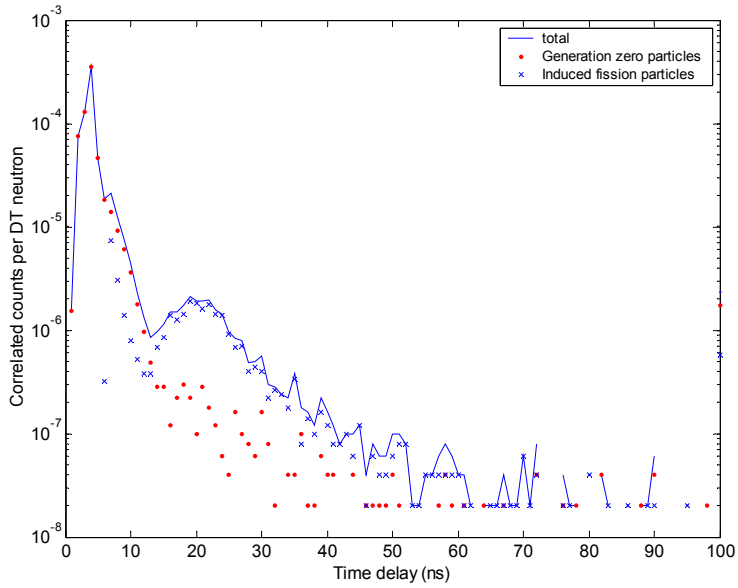

Figure 7. Source-detector cross-correlation for enriched uranium metal casting, DT source assumed isotropic, subdivided into generation zero and induced fission contributions.

A further simulation included a second casting placed at a distance of 17 cm (center of casting to center of casting) from the first. This configuration simulates the conditions of a measurement performed on a casting array with very small spacing between castings. For 50 million source neutrons emitted isotropically, the negligible background count rate increased by approximately 5%.

CONCLUSIONS

This paper presented the results of a Monte Carlo investigation of the use of an associated particle sealed tube neutron generator as the interrogation source for NMIS active measurements performed on uranium metal castings. The generator emits 14.1 MeV neutrons and has a built-in alpha detector used to define a cone of neutrons. The simulation results showed that the signatures acquired for the source and detector on the same side of the fissile sample are sensitive to sample enrichment. Further simulations showed that the background count rate is negligible for the measurement configuration in analysis.

The possibility of conducting measurements on the same side of the fissile assemblies is of great interest in the monitoring of fissile materials stored in container arrays, because the measurements could be simplified for arrays where the containers cannot be moved.

REFERENCES

[1] J.T. Mihalczo, J.A. Mullens, J.K. Mattingly, and T.E. Valentine, "Physical Description of Nuclear Materials Identification System (NMIS) Signatures," Nuclear Instruments and Methods in Physics Research Section A, 450 (August 2000) 531.

[2] S. A. Pozzi and J.T. Mihalczo, "Monte Carlo Evaluation of the Improvements in Nuclear Materials Identification System (NMIS) Resulting from a DT Neutron Generator," Proceedings of the Institute of Nuclear Materials Management 43rd annual meeting, Orlando, Florida, June 23-27, 2002.

[3] E. Padovani and S.A. Pozzi, "MCNP-PoliMi ver. 1.0. User's Manual," CESNEF-021125 Library of Nucl. Eng. Dept., Polytechnic of Milan, Italy, November 2002.