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Active-interrogation measurements of fast neutrons from induced fission in low-enriched uranium

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ABSTRACT

A detection system was designed with MCNPX-PoliMi to measure induced-fission neutrons from U-235 and U-238 using active interrogation. Measurements were then performed with this system at the Joint Research Centre in Ispra, Italy on low-enriched uranium samples. Liquid scintillators measured induced fission neutrons to characterize the samples in terms of their uranium mass and enrichment. Results are presented to investigate and support the use of organic liquid scintillators with active interrogation techniques to characterize uranium containing materials.

1. Introduction

Protection and control of nuclear fuels is paramount for nuclear security and safeguards; therefore, it is important to develop fast and robust controlling mechanisms to ensure the security of nuclear fuels. Through passive- and active-interrogation methods we can use fast-neutron detection to perform real-time measurements of fission neutrons for process monitoring. Active interrogation allows us to use different ranges of incident neutron energy to probe for different isotopes of uranium. With fast-neutron detectors, such as organic liquid scintillation detectors, we can detect the induced-fission neutrons and photons, and work towards quantifying a sample's mass and enrichment.

1.1. Nuclear safeguards

Future developments in nuclear safeguards' instruments include the use of different neutron detectors. Traditional systems rely on thermal neutron detection, while there are many benefits to using detectors that can directly measure fast neutrons from fission. The primary benefit exploited in this work is the preservation of neutron energy information via detailed detection timing. Organic liquid scintillators are the subject of this study since they allow the discrimination between photons and neutrons measured from fissile material and they have the excellent timing properties that are required by this specific form of data analysis.

1.2. Active interrogation of fissile materials

Fissile materials are of interest in the nuclear safeguards field because they help provide energy across the world, but can also be used illicitly in nuclear weapons. Methods of verifying the peaceful use of these materials rely on measuring the presence of fissile material and/or confirming that no significant quantities of known materials have been diverted. When it comes to measuring plutonium, the material's spontaneous fission probability is quite high allowing passive measurements for material characterization. Contrarily, passive measurements are often impractical when quantifying uranium, considering the spontaneous fission yield of all uranium isotopes is quite low; therefore we must rely on measuring induced fission [1]. As a result, active-interrogation techniques are required for characterizing nuclear fuels containing only uranium. A broad range of special nuclear material radiation detection applications have encountered this problem and have turned to active interrogation as a solution [2].

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1.3. Measurement campaign for characterizing uranium-oxides with liquid scintillators

Using the simulation tool MCNPX-PoliMi [3,4], a detection system was designed to measure induced-fission neutrons from U-235 and U-238. Measurements were then performed in the summer of 2011 at the Joint Research Centre (JRC) in Ispra, Italy. Low-enriched uranium (LEU) samples were interrogated and induced-fission neutrons were measured to characterize the samples in terms of their uranium mass and enrichment. The measurement system included high-energy neutron (14.1 MeV; deuterium–tritium reaction) and low-energy neutron (0.23 MeV; moderated Am–Li source) active-interrogation sources.

The purpose of the measurement campaign was to investigate the potential applicability of using organic liquid scintillators with active-interrogation techniques to characterize uranium containing materials. The presented work includes an experimental campaign that is an initial but important step in the process of assessing the application of liquid scintillators in the field of non-destructive assay and nuclear safeguards. To support the development of future systems, identifying capable simulation tools is also critical. The simulation results presented in this work support that objective. MCNPX-PoliMi simulation results were compared to the measured trends to validate the MCNPX-PoliMi code when used for active-interrogation simulations.

2. Description of LEU samples

Three well-characterized LEU samples were available for experiments at the JRC. Table 1 outlines the variation of these samples in terms of their uranium mass and enrichment. The LEU samples, specifically U_3O_8, were encased in 6.9 cm inner radius by 11.37 cm inner height aluminum canisters. The fill heights of the canisters were 7.41 cm for LEU-1 and 10.4 cm for LEU-2 and LEU-3.

Table 1
Material specifications for the three LEU samples studied at the JRC.

Sample	Uranium mass [g]	Uranium-235 mass [g]	Enrichment [%]
LEU-1	1691.93	16.60	1
LEU-2	2374.40	73.83	3.1
LEU-3	2374.96	118.19	5

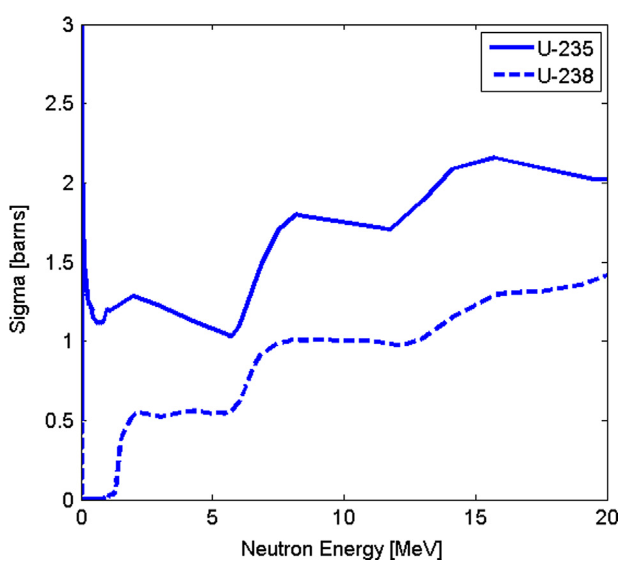

Fig. 1. Neutron-induced fission cross-sections for U-235 and U-238.The U-235 cross-section increases to over 30,000 barns at thermal neutron energies while the U-238 cross-section is less than 1 barn.

Through the use of active interrogation, we see the differences in uranium mass and U-235 enrichment by inducing fission in these three materials. The neutron-induced fission cross-sections for U-235 and U-238 are shown in Fig. 1 [5]. Based on these cross-sections, a varying induced fission response is seen by probing the three LEU samples separately with both slow and fast neutrons.

3. MCNPX-PoliMi validation

MCNPX-PoliMi was used to design the measurement system and could further be used to optimize such a measurement system and extend its applicability. To use the simulation package for such activities, it is helpful to validate the simulated active-interrogation scenarios with the measured results.

Initially, a passive Cf-252-source (approximately 1.7×10^4 neutrons per second) correlation measurement was performed with a well-characterized source to be compared with an MCNPX-PoliMi-simulated measurement. Good agreement has been observed between different organic liquid scintillation measurement systems and Cf-252 sources in the past [6,7]. These past observations are consistent with the present measurement system, as shown in Fig. 2, where the cross-correlation distributions from the measurement and the simulation agree well. The peaks in the measured neutron–photon and photon–neutron distributions near time zero are primarily due to misclassification of photons as neutrons. A relatively small amount of measured data was collected during the 1 h Cf-252 measurement, due to the low efficiency of this system, hence the statistical fluctuations in the measured results.

4. MCNPX-PoliMi active-interrogation simulations

Using MCNPX-PoliMi, a system was designed to measure induced-fission neutrons from U-235 and U-238. The system made use of a deuterium–tritium (DT) neutron generator for inducing fission in the uranium. The generator was equipped with an alpha detector to determine the time and direction of neutron emission. The liquid scintillators then measured the emitted fission neutrons configured in a manner that minimized the measurement of transmitted and scattered DT neutrons. As shown in Fig. 1, the DT neutrons (at 14.1 MeV) will induce fission in both U-235 and

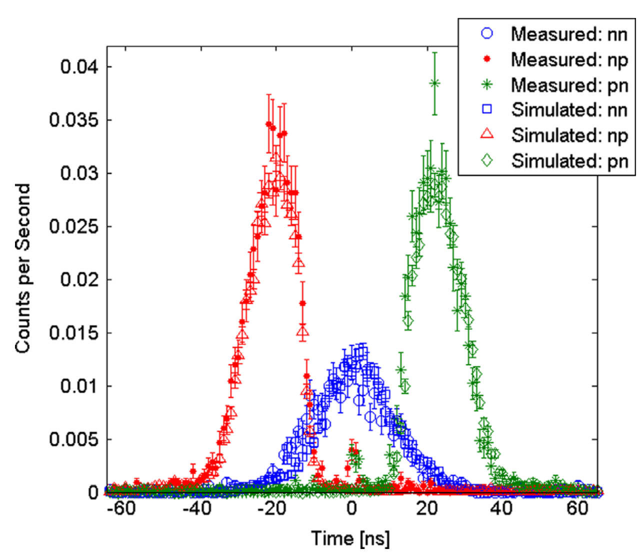

Fig. 2. Measured and MCNPX-PoliMi-simulated cross-correlation distributions for a single detector pair in conjunction with a bare Cf-252 source.