# Non-Destructive Assay of $^{235}$U and $^{239}$Pu Using a Lead Slowing-Down Spectrometer

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## INTRODUCTION

The use of a Lead Slowing-Down Spectrometer (LSDS) is considered as a possible option for non-destructive assay of fissile material in used (spent) nuclear fuel. The primary objective is to quantify the remaining fissile content of the fuel consisting mainly of $^{239}$Pu and $^{235}$U. The characterization of spent fuel is particularly important for nuclear safeguards and for determining the fuel burn-up level in view of reprocessing and recycling of used fuel. The LSDS is well suited for spent fuel testing due to its ability to assay non-destructively and directly. Several studies discussed the potential of the LSDS for spent fuel assay[1,2,3,4]. In addition, LSDS systems have been successfully used by INTERATOM and the Research Center in Karlsruhe, Germany, as well as by Rensselaer Polytechnic Institute (RPI) to assay fresh fuel pins[1,2,3,4,5].

In the framework of the LSDS Collaboration for the Material Protection and Control Technology (MPACT) Campaign, several measurements were performed in order to demonstrate the feasibility of the LSDS assay method and as a first step towards benchmark measurements.

## EXPERIMENTAL CONDITIONS

The RPI LSDS consists of a cubic lead pile (1.8 m side length) with a total weight of 72 tons. The RPI linear accelerator directs a short pulse of 55-MeV electrons on an air cooled tantalum target located in the center of the cube. Neutrons are produced via (e,γ) and (γ,n) reactions within the target. The neutrons lose energy in successive collisions with the lead leading to a correlation between the neutron energy and slowing-down time. When fissile material, such as a fuel pin, is introduced into the LSDS, fission neutrons are created. Since these fission neutrons have a significantly higher energy than the interrogating neutrons, they can easily be distinguished from the interrogation neutron flux by using a fast neutron detector such as a threshold fission chamber. Each fissile isotope gives, depending on its energy resolution-broadened fission cross section, a characteristic fission response as function of time.

In the performed experiments, $^{238}$U (and $^{232}$Th) threshold fission chambers were used. Fission chambers are essentially insensitive to gamma radiation. They are therefore particularly appropriate for fuel assay in an LSDS because of their ability to overcome the expected high gamma background caused by the spent fuel and the target bremsstrahlung. The assay detector contains about 200 mg of highly depleted $^{238}$U (4.1 ppm $^{235}$U). Such high purity is necessary to lower the detector sensitivity to the interrogation neutrons.

In the experiments, two different assay specimens were used; a fresh, low enriched $UO_2$ fuel pin from the Rensselaer Critical Facility containing about 35.2 g $^{235}$U and a PuBe source. The PuBe source serves two different purposes. Firstly, an assay of $^{239}$Pu can be performed. Secondly, the sensitivity of the assay detectors to a constant neutron and gamma background can be investigated. The PuBe source contains about 96 g of $^{239}$Pu and has an activity of about ~6 Ci (~$1.1\text{x}10^7$ neutrons/s).

## RESULTS

In a first step, only the fuel pin was inserted into a LSDS assay channel and the characteristic $^{235}$U response was measured. Then, only the PuBe source was positioned at mid depths of the LSDS interrogation channel and the assay detector response was measured. Finally, a combined assay of $^{235}$U and $^{239}$Pu signals was performed by inserting both the PuBe source and the fuel pin into the LSDS. The contribution of the $^{239}$Pu signal to the detector response was lowered by limiting the insertion depth of the source, i.e. by increasing the distance of PuBe source to detector to 35 cm. Fig. 1 shows a comparison of the three measured detector responses. The shapes of assay signal of the fuel pin and PuBe source are clearly distinguishable. The combined assay exhibits characteristics of both, so the $^{235}$U and $^{239}$Pu responses could be used as a preliminary benchmark case to test de-convoluting analysis algorithms.

All measurements were simulated with the Monte Carlo Code MCNP5[6] (shown as lines in Fig. 1). The entire lead cube, the assay specimen and the assay detector were modeled. The impurities in the lead were representatively modeled by assuming a $H_2$ content of 2 wt. ppm. With exception of the $^{238}$U sub-threshold fission peak at 10 to 20 μs, the simulated absolute detector count rate is in excellent agreement with the measurements. In particular, the assay of the PuBe source is well predicted by calculations, despite the strong self-shielding effects and the constant neutron and gamma background of the source.

## ACKNOWLEDGMENTS

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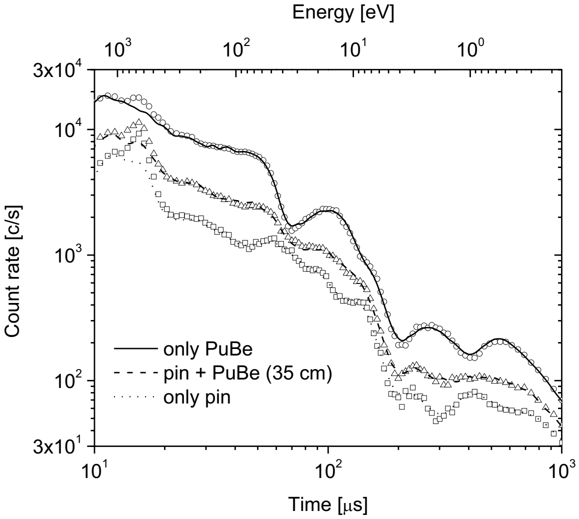

Fig.1. Measured (symbols) and simulated (lines) assay detector response of a fuel pin, a PuBe and a combined assay.

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