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Title: Differential Die-Away Instrument: Report on Fuel Assembly Mock-up Measurements with Neutron Generator

Author(s): Goodsell, Alison Victoria
Swinhoe, Martyn Thomas
Henzl, Vladimir
Rael, Carlos D.
Desimone, David J.

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Differential Die-Away Instrument: Report on Fuel Assembly Mock-up Measurements with Neutron Generator

Alison Goodsell, Martyn Swinhoe, Vladimir Henzl, Carlos Rael, David Desimone

Abstract

Fresh fuel experiments for the differential die-away (DDA) project were performed using a DT neutron generator, a 15x15 PWR fuel assembly, and nine ^{3}He detectors in a water tank inside of a shielded cell at Los Alamos National Laboratory (LANL). Eight different fuel enrichments were created using low enriched (LEU) and depleted uranium (DU) dioxide fuel rods. A list-mode data acquisition system recorded the time-dependent signal and analysis of the DDA signal die-away time was performed. The die-away time depended on the amount of fissile material in the fuel assembly and the position of the detector. These experiments were performed in support of the spent nuclear fuel Next Generation Safeguards Initiative DDA project. Lessons learned from the fresh fuel DDA instrument experiments and simulations will provide useful information to the spent fuel project.

Introduction

The differential die-away (DDA) instrument is an active interrogation system designed to measure plutonium in spent fuel assemblies via non-destructive assay. Using a short pulse of high-energy neutrons from a DT neutron generator, the DDA instrument actively interrogates a fuel assembly, thereby inducing fission in the fissile and fissionable mass. The gradual die away of the induced neutron population depends on the relative amount of multiplying material in the fuel assembly. Analysis of the die away signal reveals properties of the fuel assembly, primarily multiplication, and is implicitly a function of the initial enrichment, burnup, cooling time, and potentially other environmental factors.

This DNN R&D-funded DDA project aims to understand and advance the capability of the technique and supports the NGSI DDA project by performing experiments and simulations of fresh fuel assemblies. Lessons learned from the fresh fuel DDA experiments and simulations will provide useful information for the development and optimization of a DDA instrument for measuring spent fuel assemblies. At LANL, fresh fuel measurements using a DT neutron with a mock-up DDA instrument have been performed.

Fresh Fuel: Experiments

Fresh fuel experiments for the DDA instrument were performed in a shielded cell at LANL. A Thermo Scientific P 385 DT neutron generator was used to perform active fast neutron interrogation (Fig. 1) of a 15x15 pressurized water reactor (PWR) fresh fuel assembly (Fig. 2). A calibration of the neutron output of the generator was performed at LANL using niobium (Nb) foils for a fast flux activation measurement. The absolute neutron generator output was found to be $2.64 \cdot 10^{8}$ $n \cdot s^{-1}$ ± 6.6% at 10% duty factor and $1.88 \cdot 10^{8}$ $n \cdot s^{-1}$ ± 4.5% at 100% duty factor, with a current of 70 μA and an accelerating voltage of 125 kV.

Time-dependent spatial data were collected using a list-mode data acquisition system (DAQ), such that the time of arrival of each neutron pulse was recorded. Using the time-stamped data, we reconstructed the time-dependent DDA signal and corrected it for deadtime effects. The DAQ system, BETSY, was assembled at LANL from all commercially available parts (Fig. 3). List-mode data acquisition and analysis software developed at LANL under the DDA project were used to perform data analysis.

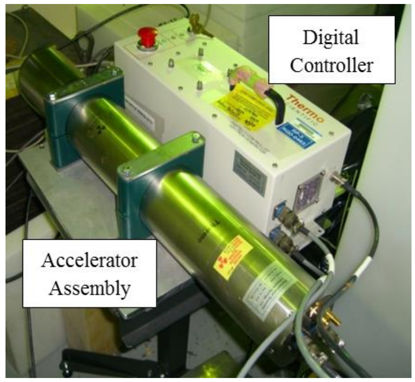

Figure 1. Thermo Scientific P 385 DT neutron generator accelerator assembly and digital controller set up inside of the LANL shielded cell. The NG can be positioned horizontally or vertically.

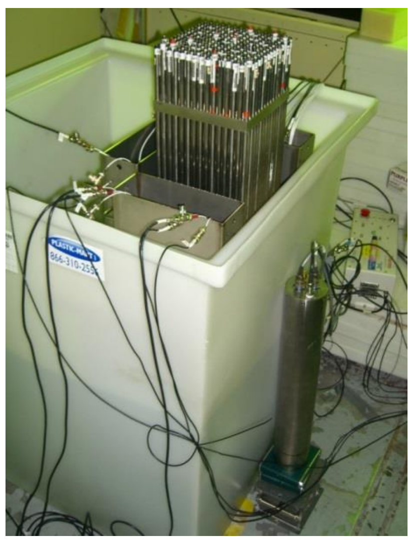

Figure 2. The original experimental setup of the DDA instrument. The 15x15 PWR fuel assembly is filled with 204 fresh LEU and DU rods. Three stainless steel enclosures hold nine ^{3}He detectors inserted into HDPE cylinders wrapped with Cd. The plastic tank is filled with ~76 cm of water, high enough to cover the detectors. The DT neutron generator sits directly outside of the tank, adjacent to the fourth side of the fuel assembly.

Figure 3. The BETSY list-mode data acquisition system is set up outside of the shielded cell.

Fresh Fuel: Analysis

The time-dependent DDA signal was acquired for all nine ^{3}He detectors around the FFA for eight different fuel enrichments: 1.96%, 1.68%, 1.38%, 1.08%, 0.79%, 0.49%, 0.20%, and empty. The different fuel enrichments were created by mixing the LEU and DU fresh fuel rods fairly uniformly in the assembly lattice (Fig. 4). The generator was run at 2500 Hz with a duty cycle of 10%, implying a pulse width of 40 µs. As seen in Fig. 5, the DDA signal first ramps up due to the DT neutron generator output in the first 20 µs and then the induced neutron population gradually dies away over the 400 µs time domain.

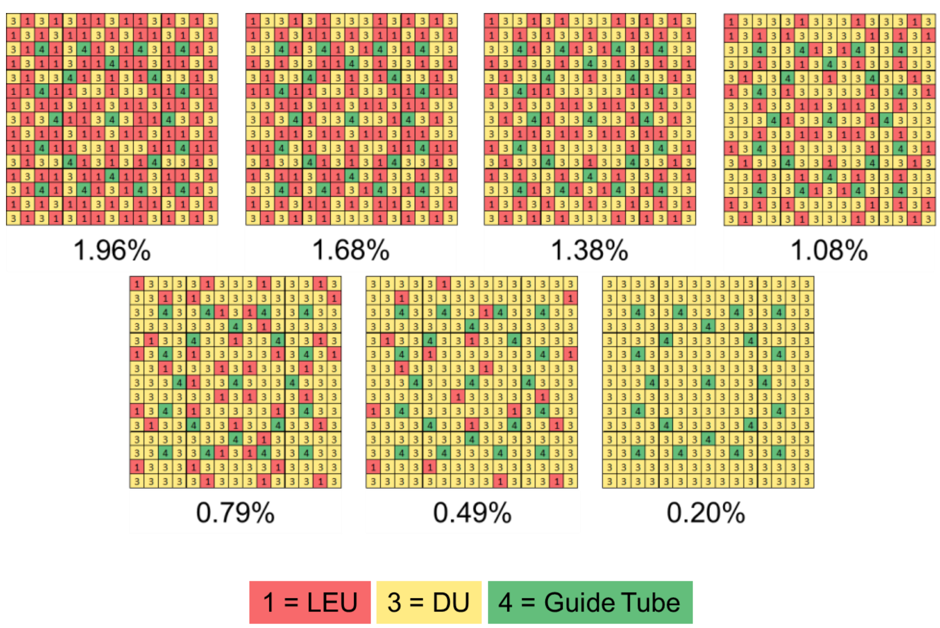

Figure 4. The different fuel enrichments were made by uniformly placing LEU and DU fresh fuel rods in the PWR fuel lattice. Identical fuel rod schematics were used in experiment and simulation.

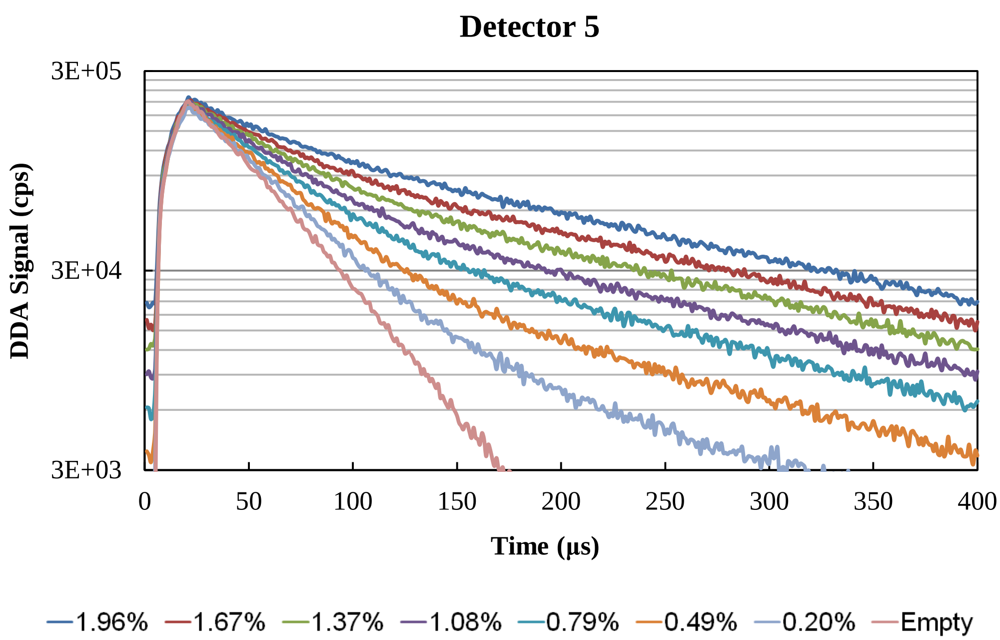

Figure 5. The time-dependent DDA signal from Detector 5 for eight fresh fuel enrichments.

The die-away time in the 100-200 µs time domain for each detector for each fuel enrichment was calculated (Fig. 6). The die-away time for each detector was found to depend on the amount of fissile material in the fuel assembly, distance from the DT neutron generator, and field of view of the FFA. The die-away time was longest for the higher fuel enrichments and for the back detectors, reaching a maximum in Detector 5. The die-away time of the empty fuel assembly reflects the die-away time of the detector packages themselves. This is particularly interesting data because it gives information on the fissile content without knowing the absolute intensity of the generator.

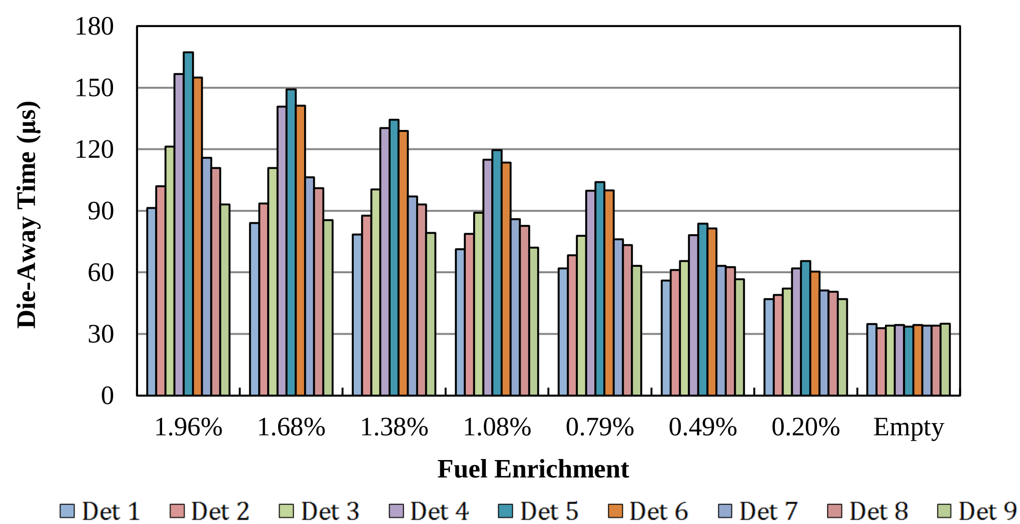

Figure 6. The experimental DDA signal die-away times in the 100-200 us time domain calculated for each of the nine detectors for eight different fuel enrichments.

Future Work

Future work for the fresh fuel DDA project includes performing experiments with an updated DDA experimental design, where the DT neutron generator is placed inside of the water tank to better replicate a cooling pool environment (Fig. 7). The new template will hold the experimental components in fixed and known positions in the water tank. In addition, faster recovery detector/electronics packages will be used to acquire data. The experimental results will be compared to simulations.

Figure 7. The updated DDA template which will hold the experimental components in fixed positions.

Conclusions

The first goal of this project aims to demonstrate that practical measurements can be made with a DDA system for spent fuel. The second aim is to confirm the quality of the simulation of the performance of the instrument made under other projects. Overall, the fresh fuel DDA experiments were successful to achieve the first goal. A large amount of data has been collected for different fuel enrichments and different detector configurations. We have made significant findings about the capabilities of different ^{3}He neutron detectors and their electronics. The experimental results have demonstrated that a DDA system can be implemented. The neutron generator output in this experiment is sufficient to be used for real spent fuel measurements and we have shown that the detectors and data acquisition system are adequate to record the data up to count rates of 1 MHz per channel (after deadtime correction). However, we have not demonstrated in these experiments the effect of the large passive neutron backgrounds that will be experienced when spent fuel is measured, but we can make estimates from simulation that show the measurement system will perform adequately in that case. Neither have we shown that the detector system will adequately handle the high gamma dose rate produced by the spent fuel assembly. The current approach to that issue is to assume the presence of a sufficient thickness gamma shielding (Pb) to reduce the gamma dose to levels that ^{3}He tubes are known to tolerate (10-20 R/hr). In future we would like to develop and test neutron detector packages that can withstand higher gamma doses. This will be the subject of further testing. We will continue to perform experiments on the full fuel assembly using the

DDA instrument and compare with the simulation results. This comparison fulfills the second goal of the project and will be reported separately. We also plan to perform experiments on potential diversion scenarios in order to determine the sensitivity of the technique.

Acknowledgements

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