LA-UR-15-22259
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Title: Differential Die-Away Instrument: Report on Benchmark Measurements and Comparison with Simulation for the Effects of Neutron Poisons

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Intended for: Report

Issued: 2015-03-30

Differential Die-Away Instrument: Report on Benchmark Measurements and Comparison with Simulation for the Effects of Neutron Poisons

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Abstract

In this report, new experimental data and MCNPX simulation results of the differential die-away (DDA) instrument response to the presence of neutron absorbers are evaluated. In our previous fresh nuclear fuel experiments and simulations, no neutron absorbers or poisons were included in the fuel definition. These new results showcase the capability of the DDA instrument to acquire data from a system that better mimics spent nuclear fuel.

I. Introduction

As nuclear fuel assemblies are burned in a reactor, a range of fission products are produced. Many of these fission products are strong neutron absorbers which affect the overall neutron population and reduce the multiplication factor of the fuel assembly. This results in a decrease to the signal magnitude, reflecting the decreased neutron population, thereby reducing the number of neutron generations, and decreasing the recorded DDA signal die-away times.

Burnable poison rods are another way neutron absorbers are introduced into fuel assemblies. At the start of a new reactor core, additional control of the neutron population is required for safety. The term "burnable" refers to a nuclide with a large absorption cross section which is converted into a low cross section nuclide after neutron absorption. These temporary control rods are placed at selected locations in the core. Different materials have been used for burnable poison rods, including borated glass and gadolinium oxide (Gd_2O_3) [1].

The low enriched uranium (LEU) and depleted uranium (DU) fresh fuel rods previously used for the experiments at LANL do not contain neutron absorbers. To emulate the presence of neutron absorbers like in spent fuel, we use specific LEU enriched poison rods containing Gd_2O_3 (3.28% ^{235}U, 5.12% Gd). There are 12 Gd_2O_3 poison rods available for our experiment.

II. Background

The National Nuclear Security Administration Office of Nonproliferation and Verification Research and Development provided funding to advance the understanding and deployment capability of the DDA instrument. Using a short pulse of high-energy neutrons from an external deuterium-tritium (DT) neutron generator, prompt fission neutrons, primarily from the fission of fissile material, are released from a fuel assembly. Due to the system being subcritical, the induced neutron population gradually dies away on the order of hundreds of microseconds. The escaping neutrons are detected by multiple helium-3 (^{3}He) detectors positioned around the fuel assembly. Previously performed spent fuel MCNPX simulations have shown that the DDA signal reveals properties of the fuel assembly, primarily multiplication, and is implicitly a function of the initial enrichment, burnup, and cooling time [2].

III. Fresh Fuel Experimental Setup and Results using Enriched Poison Rods

In early 2Q FY2015, we performed a series of experiments with the DDA instrument using the 12 Gd poison rods containing gadolinium oxide to better mimic a spent fuel environment. The Gd rods were positioned in the fuel assembly adjacent to water-filled guide tubes to be more effective thermal neutron absorbers. The experimental setup consisted of a water tank holding a DT neutron generator inside of a stainless steel pipe, three stainless steel pods holding multiple 12" active length ^{3}He detectors, and a 15x15 PWR fresh fuel assembly (Fig. 1). The data were collected using a LANL-made list-mode data acquisition system. The data were analyzed using LANL-made list-mode analysis software.

Note: Fast detectors (with CH_4-Ar fill gas) using fast post-burst recovery preamplifiers built at LANL (KM200A) were positioned around the fuel assembly at position 1, 8, and 3. Position 8 is directly opposite from position 2. Therefore, for a uniformly arranged assembly we expect statistically identical readings from these symmetrical positions.

Figure 1. The DDA experimental setup includes a DT neutron generator inside a stainless steel pipe, a 15x15 fresh fuel assembly, and three stainless steel pods holding multiple ^{3}He detectors inserted into HDPE, Cd-wrapped sleeves.

The DT neutron generator was operated at 2500 Hz producing short, 20 μs long pulses to actively interrogate the fresh fuel assembly. The 12 Gd poison rods were positioned uniformly throughout the fuel assembly; the Gd rods were not moved during the experimental campaign (Fig. 2). The time-dependent DDA signal was reconstructed from the list-mode data (Fig. 3). The presence of 12 Gd poison rods positioned uniformly throughout the assembly caused the neutron population to decrease, which reduced the number of neutron generations, thereby decreasing the DDA signal die-away time magnitudes (Table I). For the highest enriched case of 1.68% ^{235}U, the die-away time of the DDA signal in the front three detectors (Detectors 1, 8, and 3) decreased by approximately 12% in the 70-100 μs time domain when the

12 Gd rods were inserted uniformly in the fuel assembly. (For detector positions, see Fig. 4.) From DDA spent fuel simulations, the die-away time in the 100-200 μs time domain decreased by approximately 50% between a fresh and fully burned (50 GWd/tU) fuel assembly. Therefore, the 12% decrease in die-away time in the fresh fuel experiments with and without Gd poison rods roughly corresponds to a 10 GWd/tU burnup. The change to the die-away time of the front detectors lessened as the enrichment of the fuel assembly decreased, but there was still a noticeable change for the 0.80% and 0.22% ^{235}U configurations.

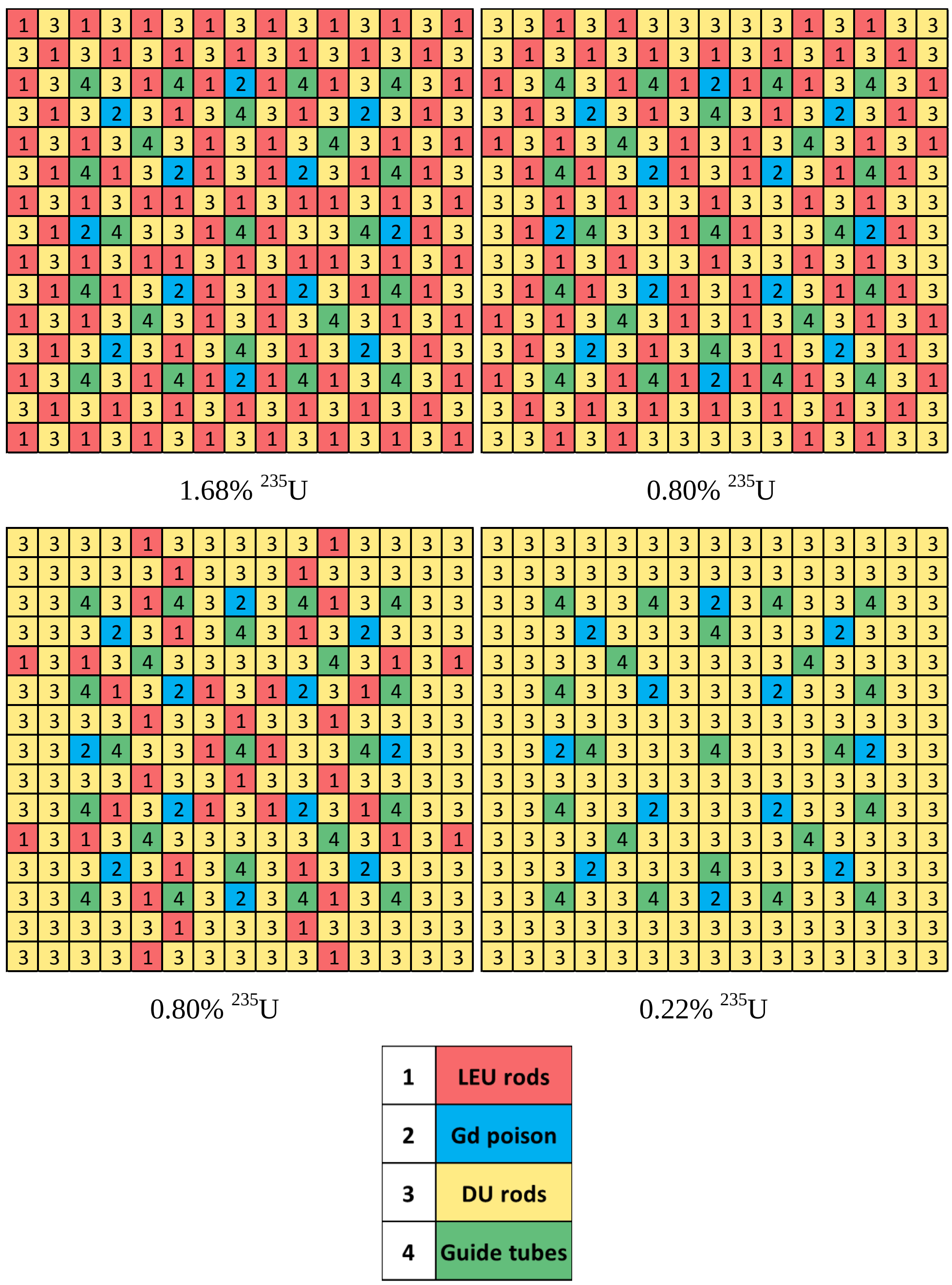

Figure 2. Four fresh fuel enrichments with 12 Gd rods were used during the experimental campaign.

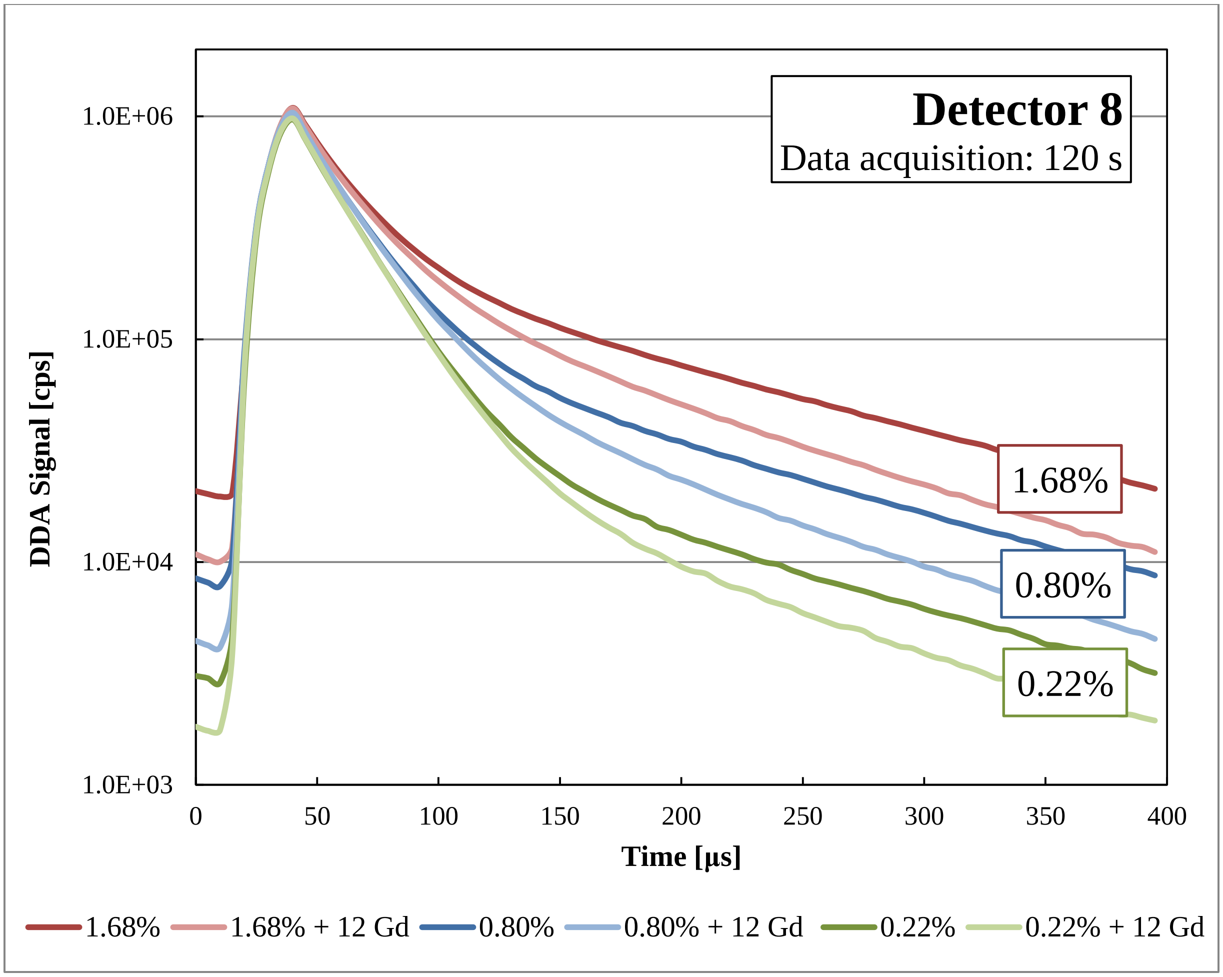

Figure 3. Experimental data comparing the DDA signal for three enrichments (1.68%, 0.80%, and 0.22% ^{235}U) with and without twelve enriched poison (Gd) rods.

Table I

The experimental DDA signal die-away time in the 70-100 µs time domain was determined for Detectors 1, 8, and 3 for three fresh fuel enrichments (1.68%, 0.80%, and 0.22% ^{235}U) and the empty case. For detector positions, see Fig. 4.

	Experimental Data 70-100 µs Time Domain Die-Away Times [µs]						
	1.68%		0.80%		0.22%		Empty
	No Gd	12 Gd	No Gd	12 Gd	No Gd	12 Gd	No Gd
Detector 1	36.6	33.1	25.7	23.9	19.9	19.3	15.7
Detector 8	44.9	40.1	33.0	30.8	26.1	25.5	22.1
Detector 3	No data	43.4	34.8	32.2	26.9	26.0	22.4

IV. MCNPX Simulation Results with Gadolinium Poison Rods

MCNPX simulations of the experimental setup were performed for a range of fresh fuel enrichments, with and without Gd poison rods (Fig. 4). The time-dependent DDA signal of the fresh fuel assembly with and without 12 Gd rods was plotted (Fig. 5). From previously performed calibration, the output of the DT neutron generator was estimated as $1.8 \cdot 10^8$ n/s ± 10% [3]. The die-away time of the simulated DDA signal was determined for multiple detector positions and fuel enrichments, with and without Gd rods (Table II). Wrap-around effects from the previous neutron generator pulse were taken into account [3]. However, any effects from delayed neutrons were not due to the time cutoff of the tally. Delayed neutrons may act as a constant background to the DDA signal. In the future, we may further investigate these effects.

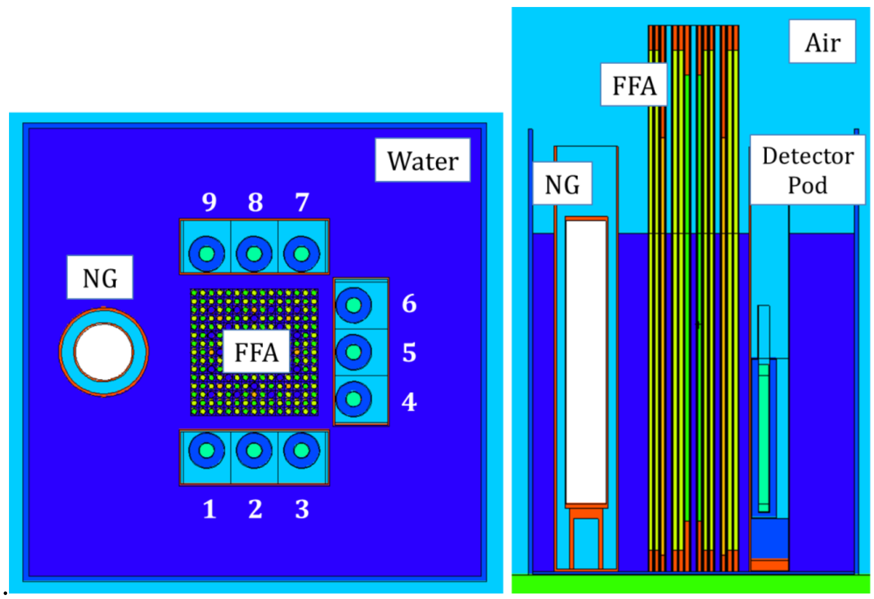

Figure 4. The MCNPX simulation of the fresh fuel setup with 12 Gd poison rods was modeled to mimic the experimental setup.

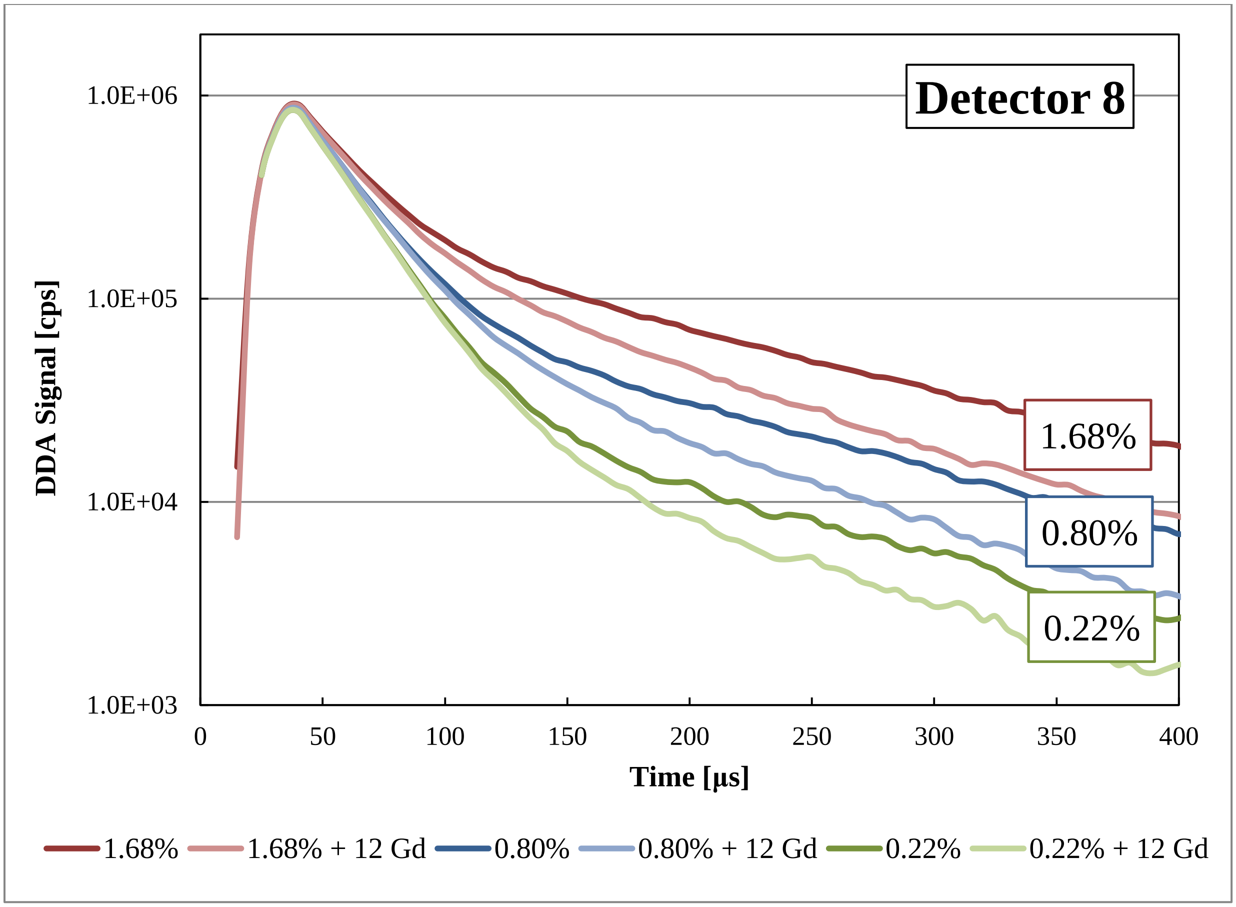

Figure 5. Simulated results of the DDA signal for three enrichments (1.68%, 0.80%, and 0.22% ^{235}U) with and without twelve enriched poison rods (Gd) were compared.

Table II

The simulated DDA signal die-away time in the 70-100 µs time domain was determined for Detectors 1, 8, and 3 for three fresh fuel enrichments (1.68%, 0.80%, and 0.22% ^{235}U) and the empty case.

	MCNPX Simulation 70-100 µs Time Domain Die-Away Times [µs]						
	1.68%		0.80%		0.22%		Empty
	No Gd	12 Gd	No Gd	12 Gd	No Gd	12 Gd	No Gd
Detector 1	36.9	32.7	25.9	23.9	20.0	19.3	15.5
Detector 8	45.2	39.6	33.4	30.9	26.1	25.0	21.6
Detector 3	48.0	40.8	33.9	31.2	25.9	25.2	21.3

V. Comparison

The results from the experiments were compared with the MCNPX simulations. Qualitatively, the time-dependent behavior of the DDA signal from simulation and experiment trends well for multiple enrichments (Fig. 6). The discrepancies visible in the figures may be due to the presence of delayed neutrons which were not simulated in MCNPX due to the time cutoff of the tally. The delayed neutrons would affect the relative magnitude of the DDA signal, producing a greater effect in the later time domains.

The relative differences of the die-away times of the DDA signal in the 70-100 μs time domain from the experimental data and simulation results were compared (Fig. 7). On average, the relative difference between the experimental and simulated die-away times in the 70-100 μs time domain was ±2% on average.

VI. Conclusions

To better mimic a spent fuel environment, enriched Gd poison rods were added to the fresh fuel configuration to test the performance of the DDA instrument. MCNPX can accurately reproduce the experiment and model the presence of neutron absorbers in regards to the reduced neutron population and decreased die-away times. The dynamic evolution of the DDA signal in both simulation and experiment trended well with detector position and fresh fuel enrichment. The relative difference between the experimental and simulated DDA signal die-away time in the 70-100 μs time domain was ±2% on average.

VII. Acknowledgements

The authors would like to acknowledge the support of NNSA DNN R&D for this project.

VIII. References

[1] J. Lamarsh, Introduction to Nuclear Engineering, Reading, MA: Addison-Wesley, 1975.

[2] V. Henzl, M. Swinhoe, S. Tobin and H. Menlove, "Measurement of the Multiplication of a Spent Fuel Assembly with the Differential Die-Away Method Within the Scope of the Next Generation Safeguards Initiative Spent Fuel Project," *Journal of Nuclear Materials Management,* vol. XL, no. 3, pp. 61-69, 2012.

[3] A. Goodsell, V. Henzl, M. Swinhoe, C. Rael and D. Desimone, "Differential Die-Away Instrument: Report on Comparison of Fuel Assembly Experiments and Simulation," Los Alamos National Laboratory, Los Alamos, 2015.

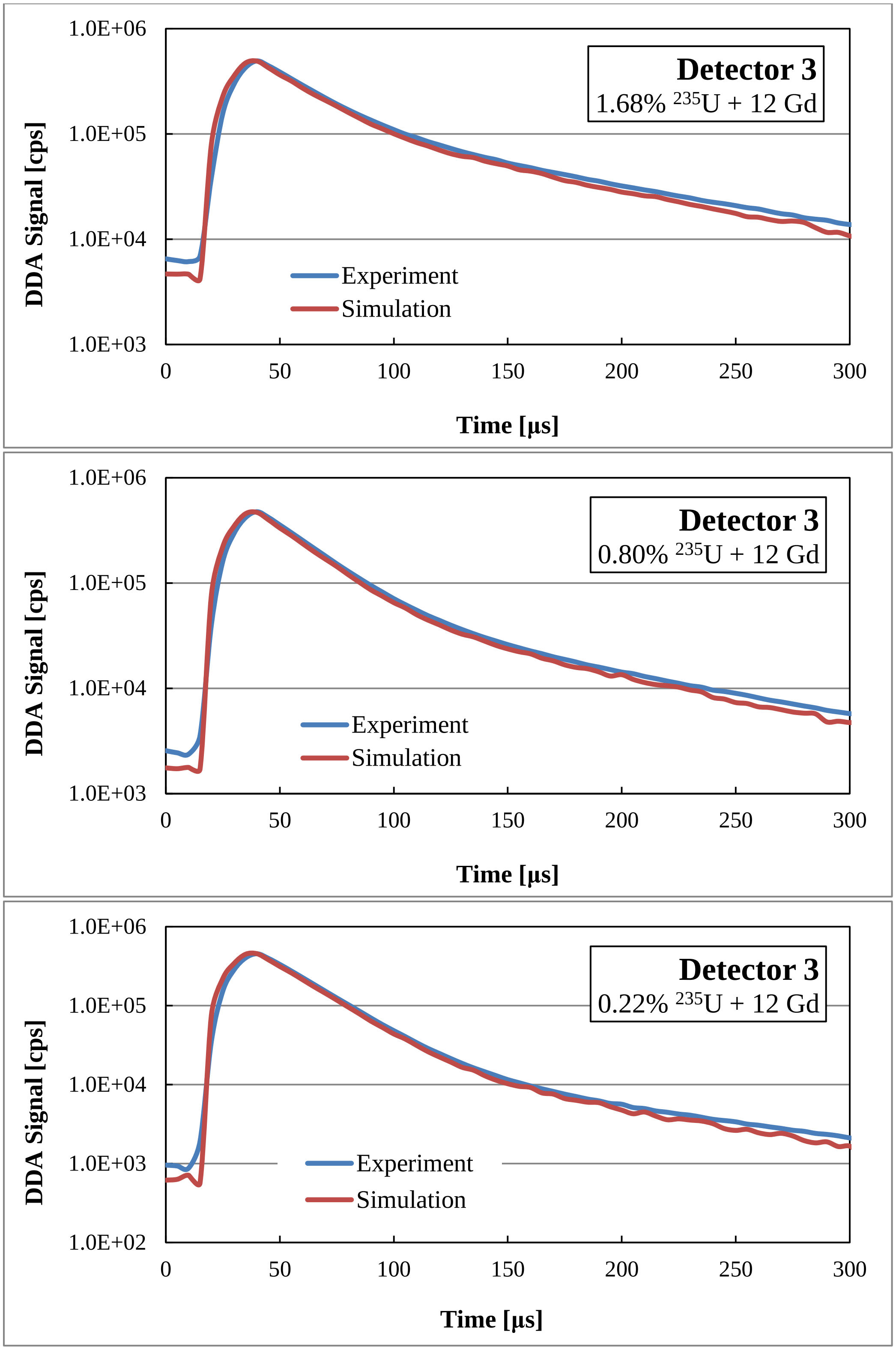

Figure 6. The time-dependent signal from Detector 3 for three fresh fuel enrichments including the 12 enriched poison Gd rods (1.68%, 0.80%, and 0.22% ^{235}U) were plotted.

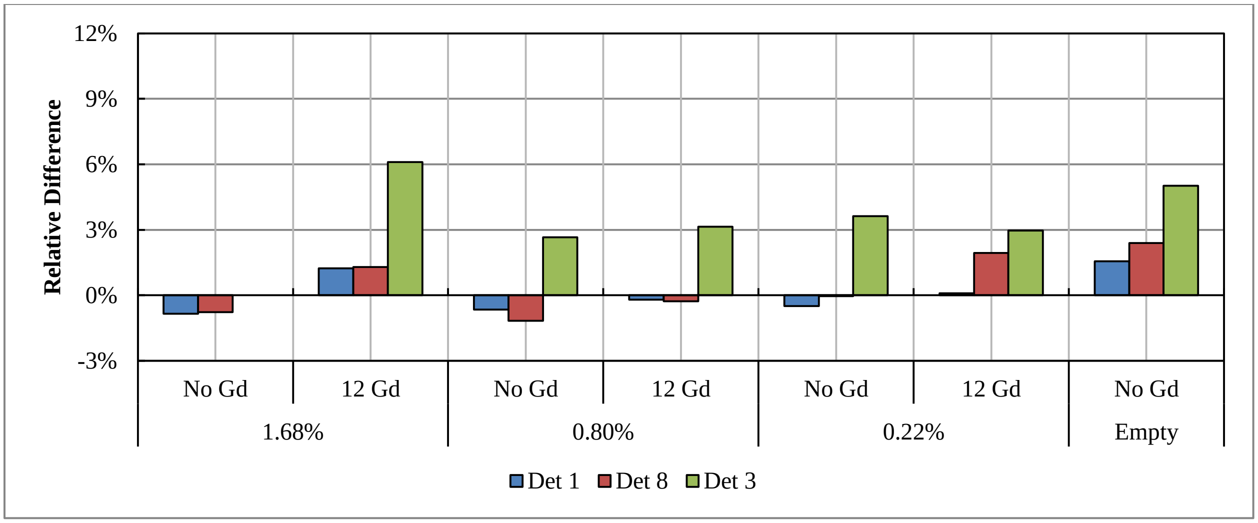

Figure 7. The relative differences between the experimental and simulated die-away times in the 70-100 μs time domain for detectors 1, 8, and 3 for several fresh fuel enrichments (with and without the Gd poison rods) were determined. There was no data available for Detector 3 for the 1.68% ^{235}U “No Gd” case.