LA-UR-14-27369

Title: Differential Die-Away Instrument: Report on Neutron Detector Recovery Performance and Proposed Improvements

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Intended for: Report

Issued: 2014-09-22

Differential Die-Away Instrument: Report on Neutron Detector Recovery Performance and Proposed Improvements

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Abstract

Four helium-3 (^{3}He) detector/preamplifier packages (¾"/KM200, DDSI/PDT-A111, DDA/PDT-A111, and DDA/PDT10A) were experimentally tested to determine the deadtime effects at different DT neutron generator output settings. At very high count rates, the ¾"/KM200 package performed best. At high count rates, the ¾"/KM200 and the DDSI/PDT-A111 packages performed very well, with the DDSI/PDT-A111 operating with slightly higher efficiency. All of the packages performed similarly at mid to low count rates. Proposed improvements include using a fast recovery LANL-made dual channel preamplifier, testing smaller diameter ^{3}He tubes, and further investigating quench gases.

Introduction

The differential die-away (DDA) instrument is an active interrogation system which will be operated directly adjacent to spent nuclear fuel (SNF) assemblies inside of a cooling pool. The passive neutron background from an assembly (mainly due to spontaneous fission and (α,n) reactions) will vary with initial enrichment, burnup, and cooling time; each DDA detector will register on the order of 10^4-10^5 n/s from passive background. The DDA instrument needs to operate in these extremely high count rate environments and recover quickly after the pulse of 14.1 MeV neutrons from the NG. Faster post-burst recovery detectors and electronics are required to cope with this challenge. Previous DDA instruments for assaying nuclear waste were operated in much lower count rate environments and delayed acquiring data until >500 μs after the neutron generator burst. However, the DDA instrument for nuclear safeguards applications will begin acquiring data almost immediately after the neutron generator pulse (<50 μs).

Neutron Detector Recovery Performance

By leveraging work sponsored by other projects requiring fast recovery detector electronics, the DNN R&D-funded DDA project at LANL has experimentally tested and analyzed different detector/preamplifier packages. In July 2014, four detector/preamplifier combinations were tested using a DT neutron generator.

Three 1" diameter, Reuter-Stokes ^{3}He tubes at 4 atmospheres (atm) with different quench gases and preamplifiers were tested [1]. The DDSI detector has a 15" active length with tetrafluoromethane (CF_4) quench gas and operates at 1680 V. The DDA detectors are 12" active length with carbon dioxide (CO_2) fill gas and operate at 1680 V. The "PDT-A111" preamplifier uses a PDT preamplifier with an AMPTEK A111 chip for faster deadtime recovery [2]. PDT-A111 preamps were paired with both the DDSI and DDA tube. The ¾"/KM200 detector/electronics package has 15" active length, ¾" diameter, ^{3}He filled tube with CF_4 quench gas and operates at 1940 V. The LANL-produced ¾"/KM200 package was developed to optimize the detector and pre-amplifier designs as a unit, rather than separately [3]. The shorter deadtime, faster recovery ¾"/KM200 detector has redesigned electrodes, including a thicker anode to decrease the detector charge collection path, reduced space charge effects caused by high neutron and gamma fluxes, and improved gamma tolerance (reduced energy deposition paths for electrons) which will be important in a spent fuel environment. The ¾”/KM200 preamplifier uses a special filter to remove double pulsing and was designed to operate specifically with this particular detector [4]. The characteristics of the detector/electronics packages are described in Table I.

Table I. Description of the detector/electronics packages tested using the DT neutron generator.

Detector/Preamp Package	Active Length (in.)	Diameter (in.)	Gas Pressure (atm)	Quench Gas	High Voltage (V)
¾”/KM200	15	0.75	6	CF_4	1940
DDSI/PDT-A111	15	1	4	CF_4	1680
DDA/PDT-A111	12	1	4	CO_2	1680
DDA/PDT10A	12	1	4	CO_2	1680

The four packages were positioned equidistant (~21”) from a DT neutron generator to test their ability to recover after a massive burst of high-energy neutrons (Fig. 1). The detectors were inserted into high-density polyethylene (HDPE) cylinder sleeves wrapped with cadmium (Cd).

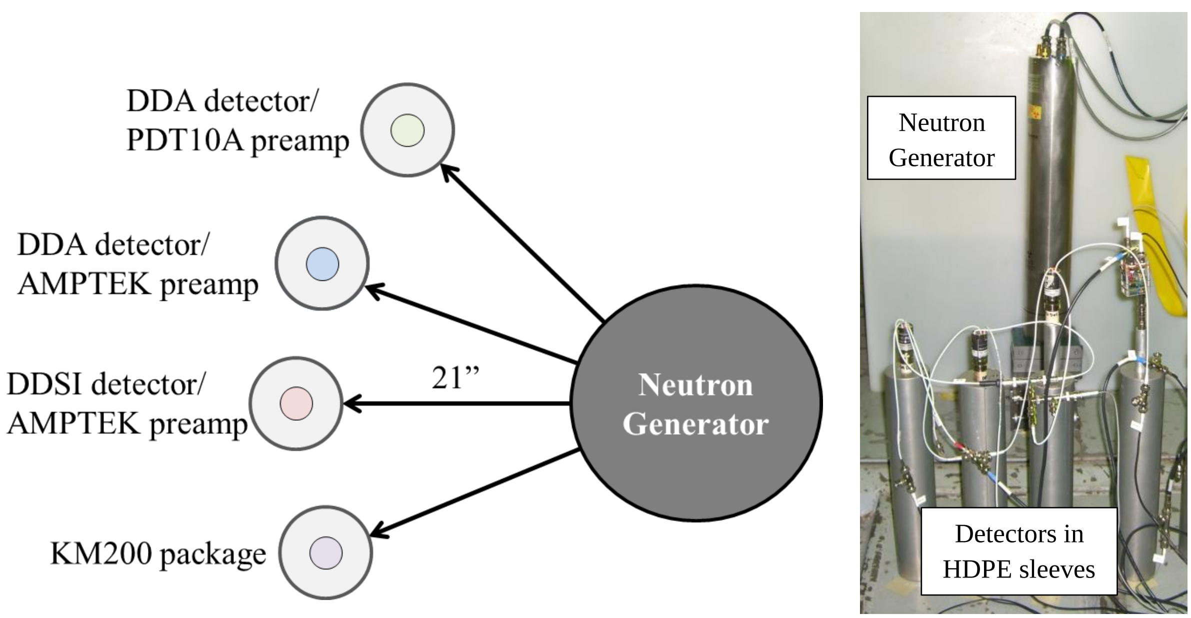

Figure 1. Four different detector and electronics packages were positioned equidistant (~21”) from the DT neutron generator to test their ability to operate in a high count rate environment.

The detector/preamplifier packages were compared by analyzing the individual packages’ deadtime effects and detector efficiencies. The capabilities of the packages were tested by operating the DT neutron generator at multiple outputs: high, medium, low, and very low. The non-deadtime corrected DDA signals were plotted (Fig. 2).

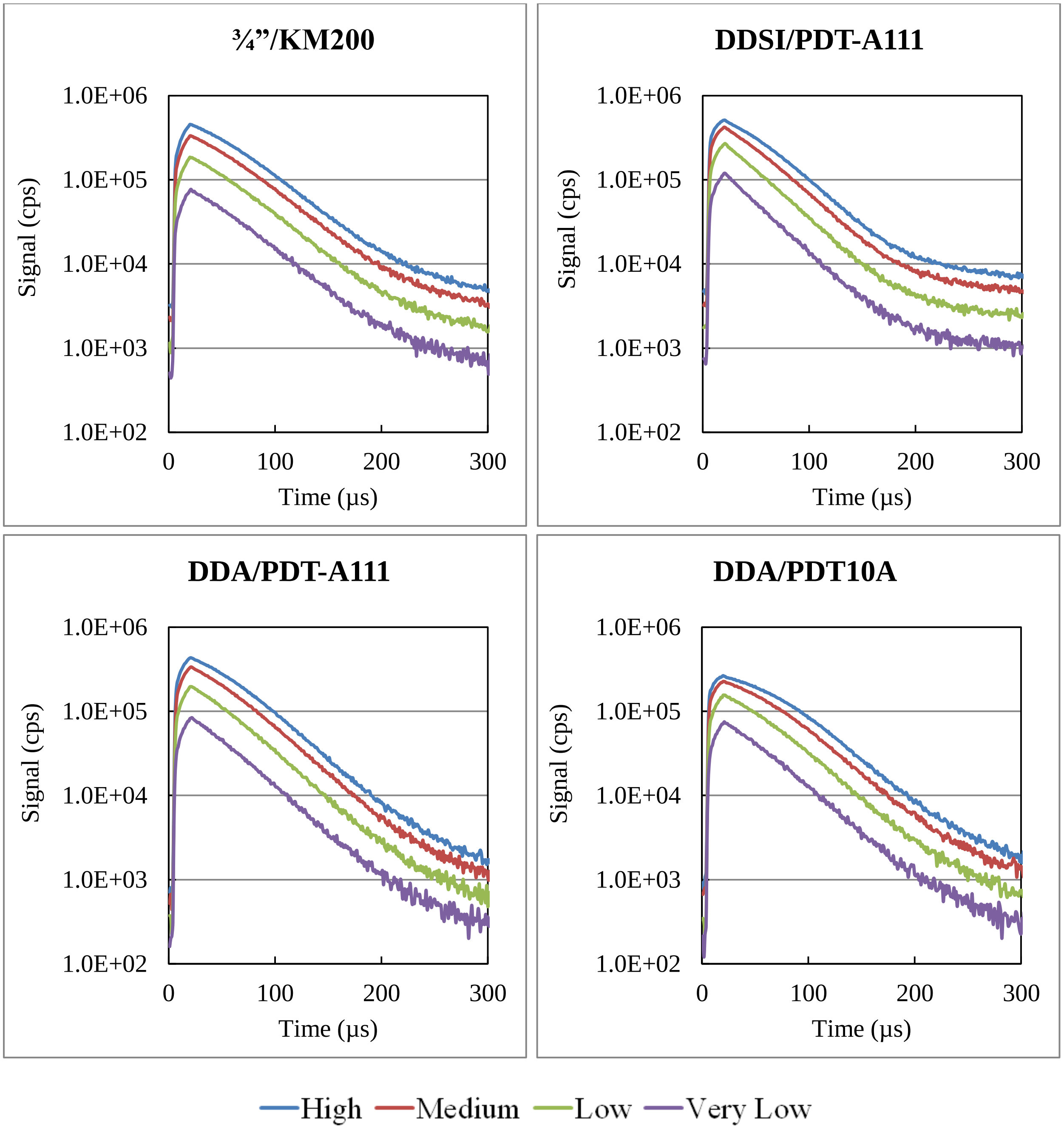

Figure 2. The non-deadtime corrected DDA signal in counts per second for the four detector/preamplifier packages approximately 21" from the DT neutron generator at outputs of high, medium, low, and very low.

The DDA signals were normalized to the high output signal using an exponential fit evaluated at 225 μs (a time when deadtime should not greatly affect the signal) such that if there were no deadtime effects, the time-dependent signals at different neutron generator outputs would overlap. However, due to deadtime effects at higher output settings, there were obvious differences in the signals (Fig. 3).

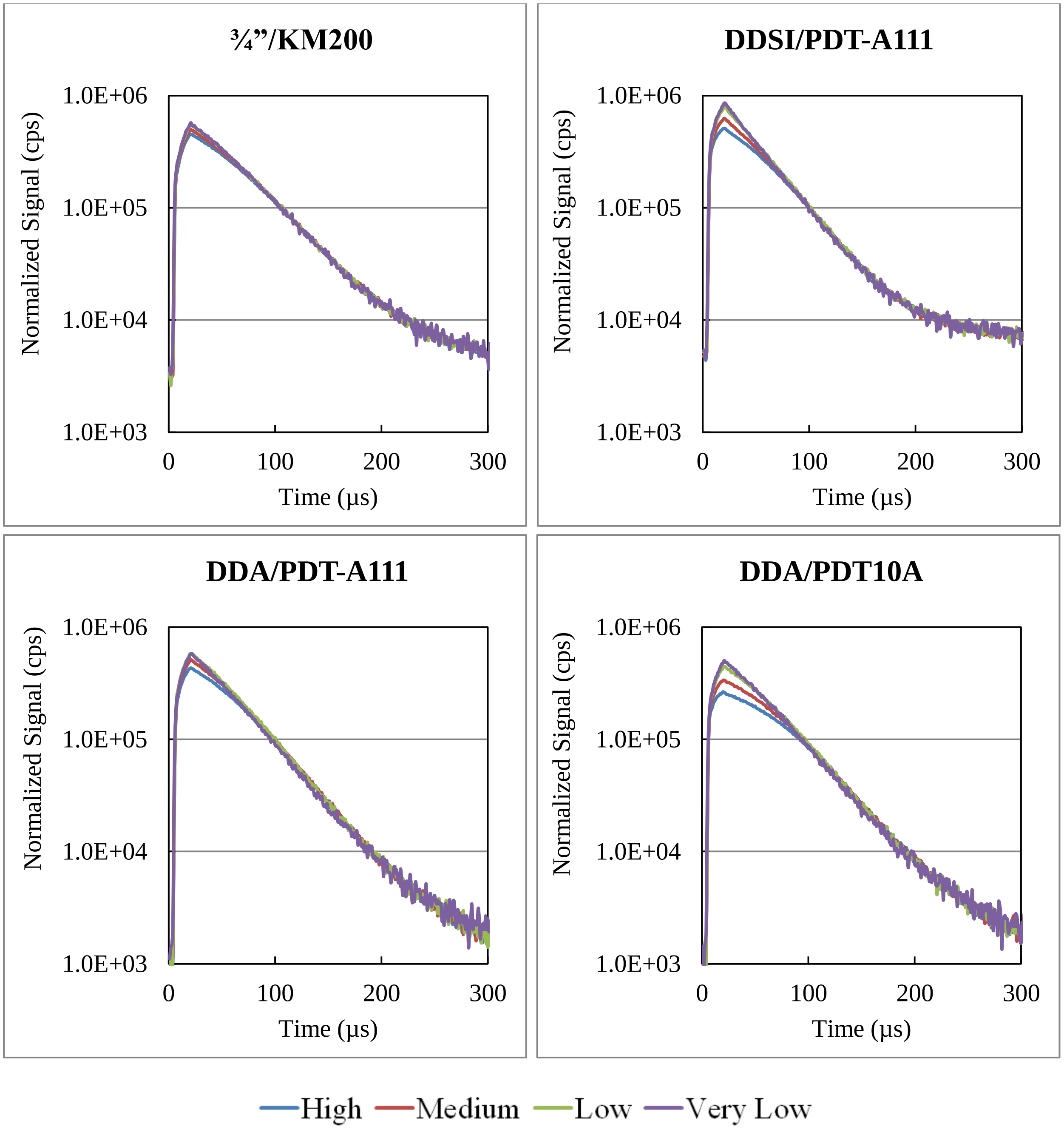

Figure 3. The DDA signals for each detector/electronics package were normalized to the high DT neutron generator output using an exponential fit evaluated at 225 µs. Differences between the overlapping time-dependent DDA signals are due to deadtime effects.

We determined the respective deadtime coefficients of the packages using the infinite exponential method in Eq. (1), where $\dot{S}_{DT}$ is the deadtime corrected count rate, $\dot{S}_M$ is the measured count rate, and d is the deadtime correction coefficient. Different deadtime coefficients were evaluated until all of the time-dependent signals for the respective detectors/electronics overlapped (Fig. 4).

$$\dot{S}_{DT} = \dot{S}_M \cdot \exp(d \cdot \dot{S}_{DT}) \cong \dot{S}_M \cdot \exp(d \cdot \dot{S}_M \cdot \exp(d \cdot \dot{S}_M \cdot \exp(d \cdot \dot{S}_M \cdot \exp(d \cdot \dot{S}_M \ldots)))) \qquad (1)$$

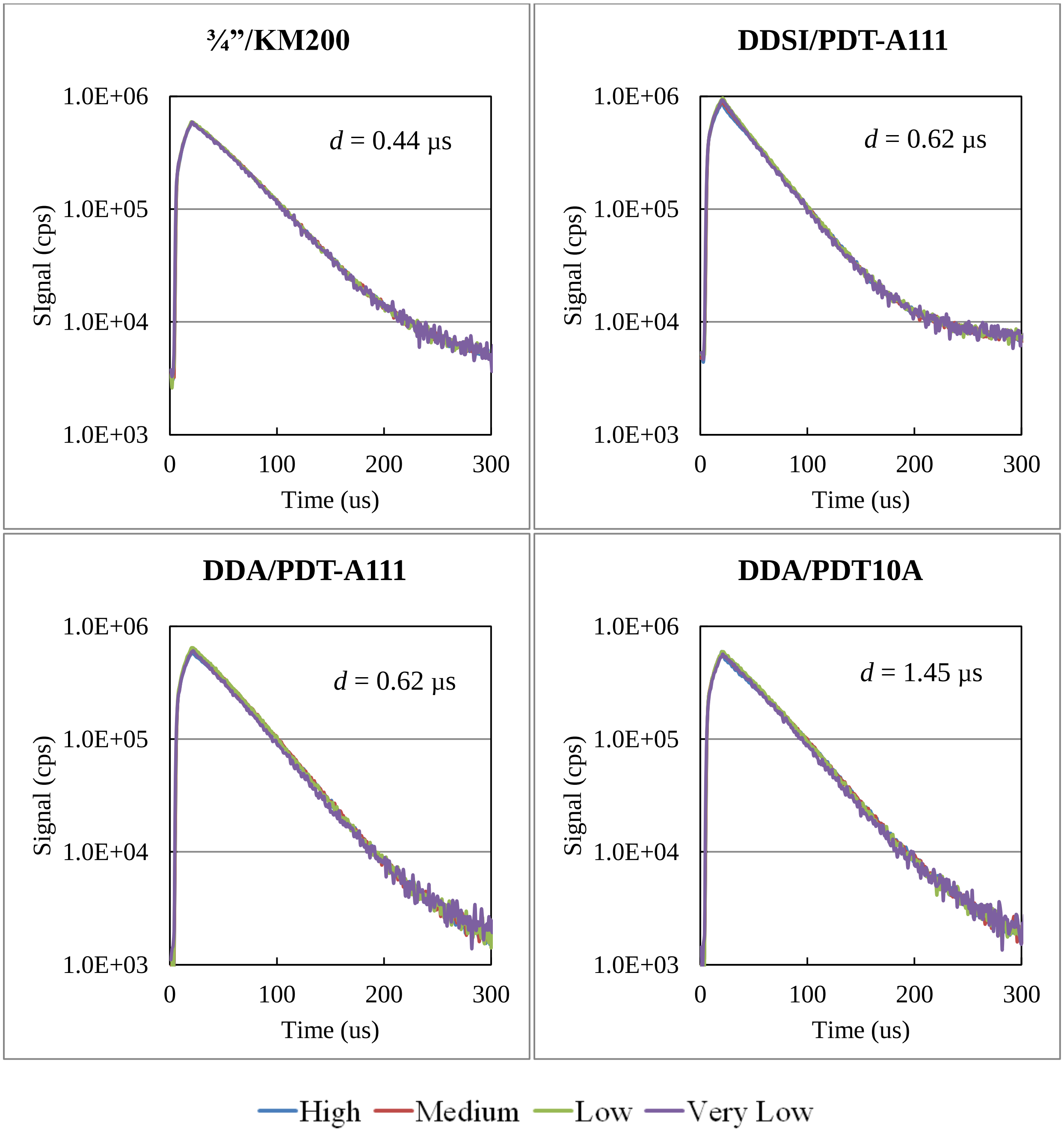

Figure 4. The normalized, deadtime corrected signals from the four different detector/electronics packages with different deadtime coefficient values.

By analyzing the shape and magnitude of the signals from the different detector/electronics packages, after deadtime correction the ¾”/KM200 and the DDSI/PDT-A111 package appear to have the highest efficiencies and are least affected by deadtime (Fig. 5). The DDSI/PDT-A111 package appears to have a higher efficiency (due to being a 1” diameter ^{3}He tube) than the ¾”/KM200 (a ¾” diameter tube). However there are minor deadtime affects visible at the maximum DT neutron generator setting directly after the burst (20 μs) in the DDSI/PDT-A111 signal, with a slight deformation at the peak of the ramp up.

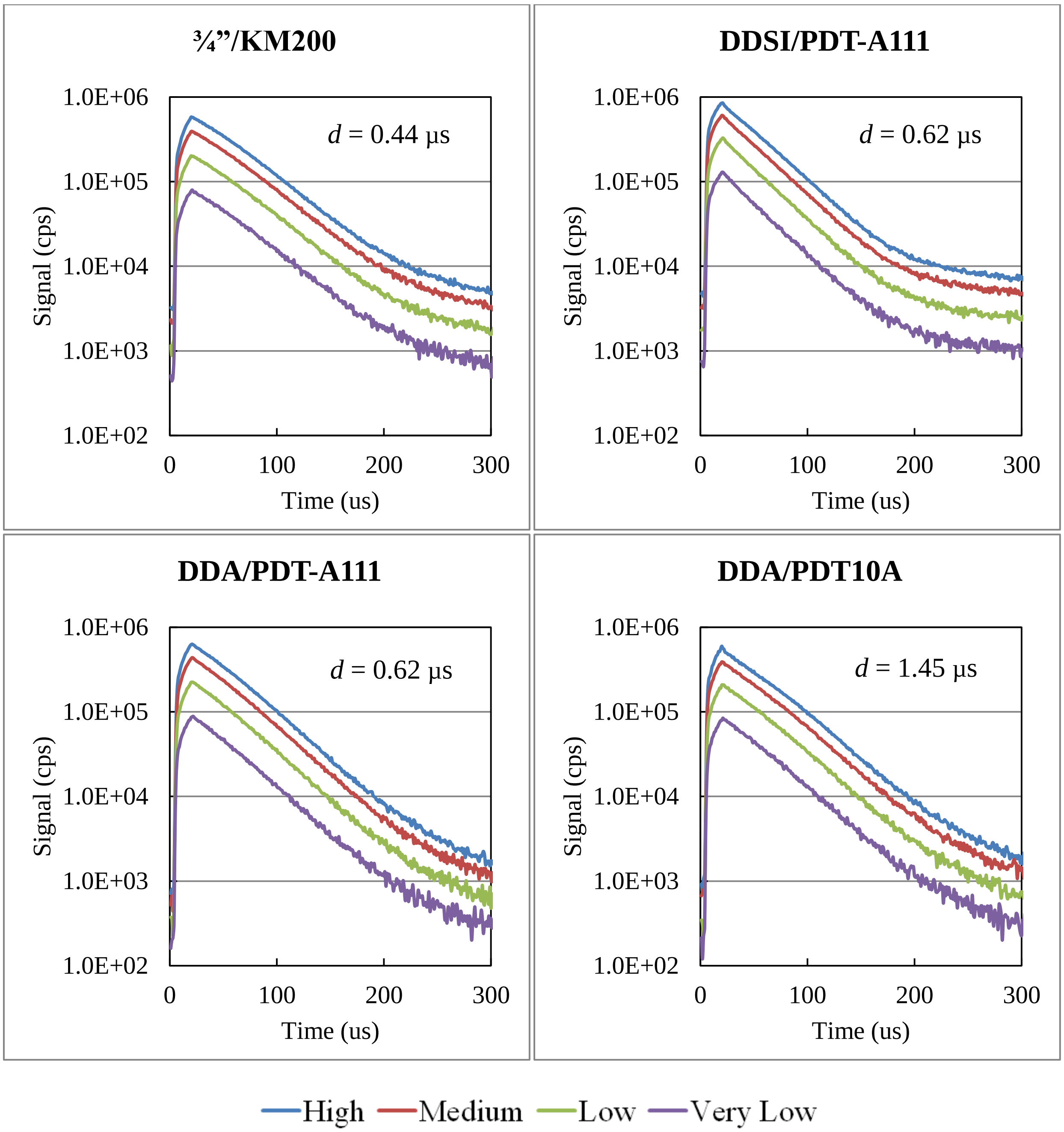

Figure 5. The unnormalized, deadtime corrected signals from the four different detector/electronics packages for the four DT neutron generator output settings.

Overall at 21” from the DT neutron generator, all of the detector/preamplifier packages were able to withstand the count rate but with different deadtime coefficients (*d*). The deadtime correction coefficients for the four detector/electronics packages were: ¾”/KM200 with 0.44 µs, DDSI/PDT-A111 with 0.62 µs, DDA/PDT-A111 at 0.62 µs, and the DDA/PDT10A at 1.45 µs. The ¾”/KM200 and the detectors paired with the PDT-A111 preamplifier recover very quickly and are able to withstand high countring rates. The PDT10A preamplifier does not recover as quickly following the DT neutron generator burst as seen by the oddly shaped peak in Fig. 5 for the high neutron generator output. (There is a similar, but smaller effect on the DDSI/PDT-A111 detector). These tests show that the ¾”/KM200 package can operate up to deadtime correction count rates of at least 8×10^5 cps. The detector package designed for the DDSI system (DDSI/PDT-A111) will operate correctly above 2×10^5 cps, which is the estimated upper limit for the DDSI implementation. Incidentally it may be noted that these tests also confirm that the data acquisition system is capable of correctly recording data at these rates.

We also wanted to test the counting limits of the detector/electronics packages. We moved the packages as close as possible to the DT neutron generator (Fig. 6) and recorded the signal at different output settings (Fig. 7).

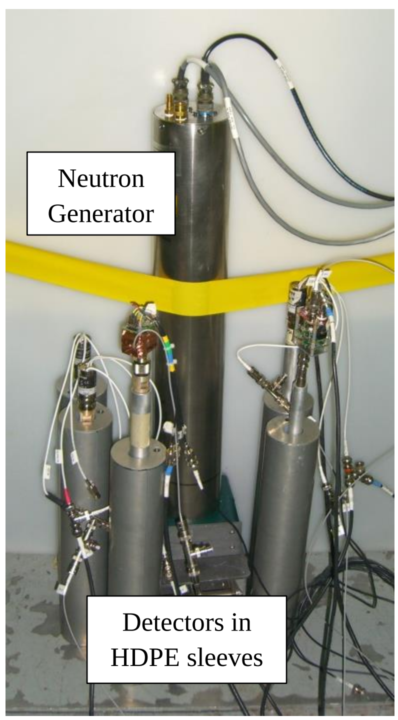

Figure 6. The experimental set up of the detector/preamplifier packages placed as close as possible to the DT neutron generator.

In addition to the deadtime effects discussed above (and which can be corrected), all detector/electronics packages show additional counting rate effects in the recorded time-dependent signal. The DDA/PDT10A package performed particularly poorly, with large fluctuations in the detected signal. The ¾”/KM200, DDSI/PDT-A111, and DDA/PDT-A111 packages were also all affected by saturation of the count rate, as seen by the flattened peak directly after the DT neutron generator burst (20 µs).

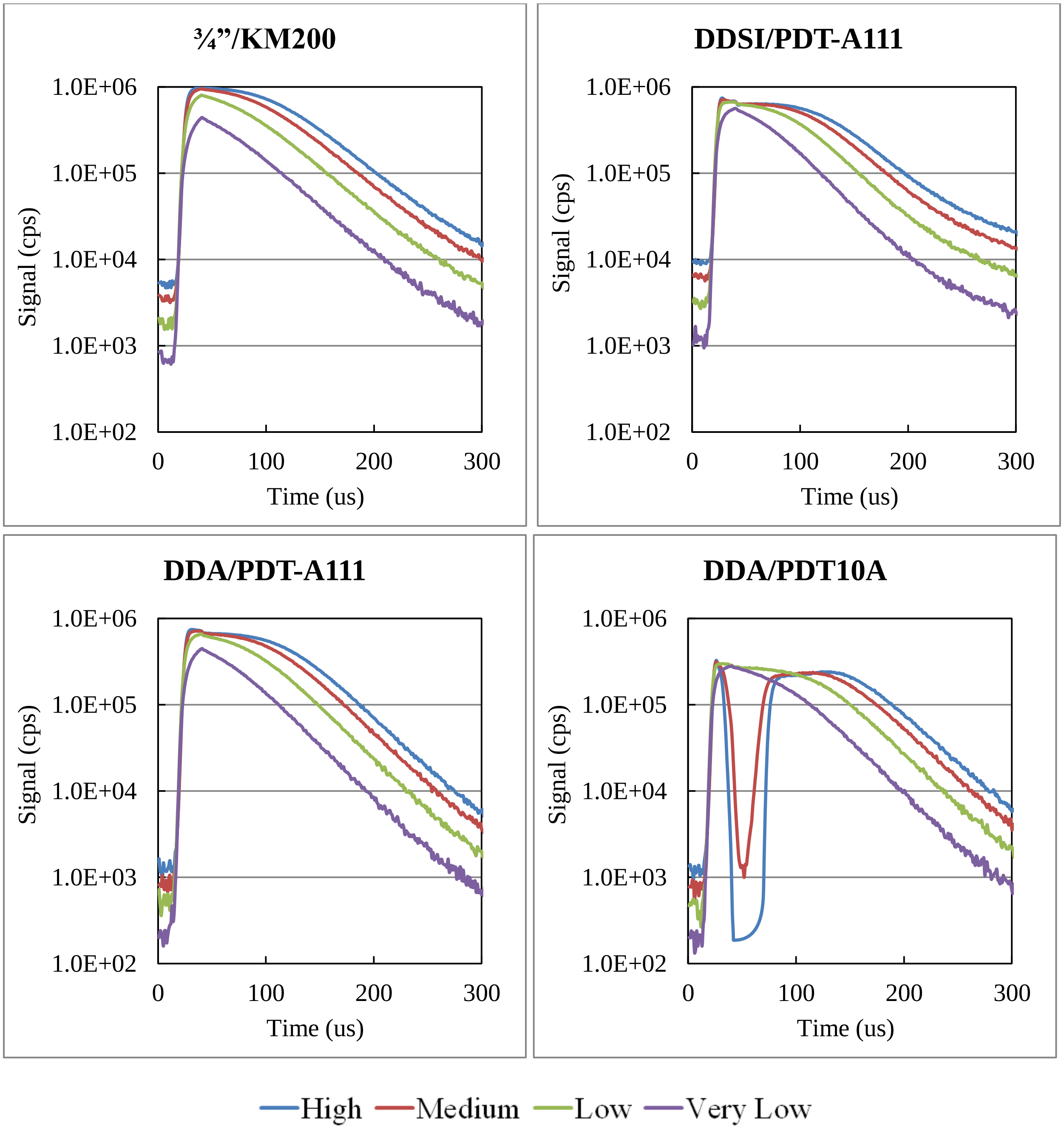

Figure 7. The non-deadtime corrected signal from the four detector/preamplifier packages at the closest position to the DT neutron generator.

For the closer positioning of the detectors, we performed the identical deadtime correction methods to the detector/preamp signals. The deadtime effects are much more apparent when the packages are directly adjacent to the DT neutron generator, as expected. As seen in Figure 8, the ¾"/KM200 packages performed best out of the four detector systems. Even at extremely high count rates, the ¾"/KM200 signal still showed the expected neutron generator ramp up behavior. The other three packages all displayed discontinuities due to abnormalities in the signal from counting rate effects. The DDA/PDT10A package was affected the most.

This second set of tests shows that the ¾"/KM200 package can operate correctly at deadtime corrected rates above 1×10^6 cps and the DDSI/PDT-A111 package can operate correctly at rates approaching 1×10^6 cps.

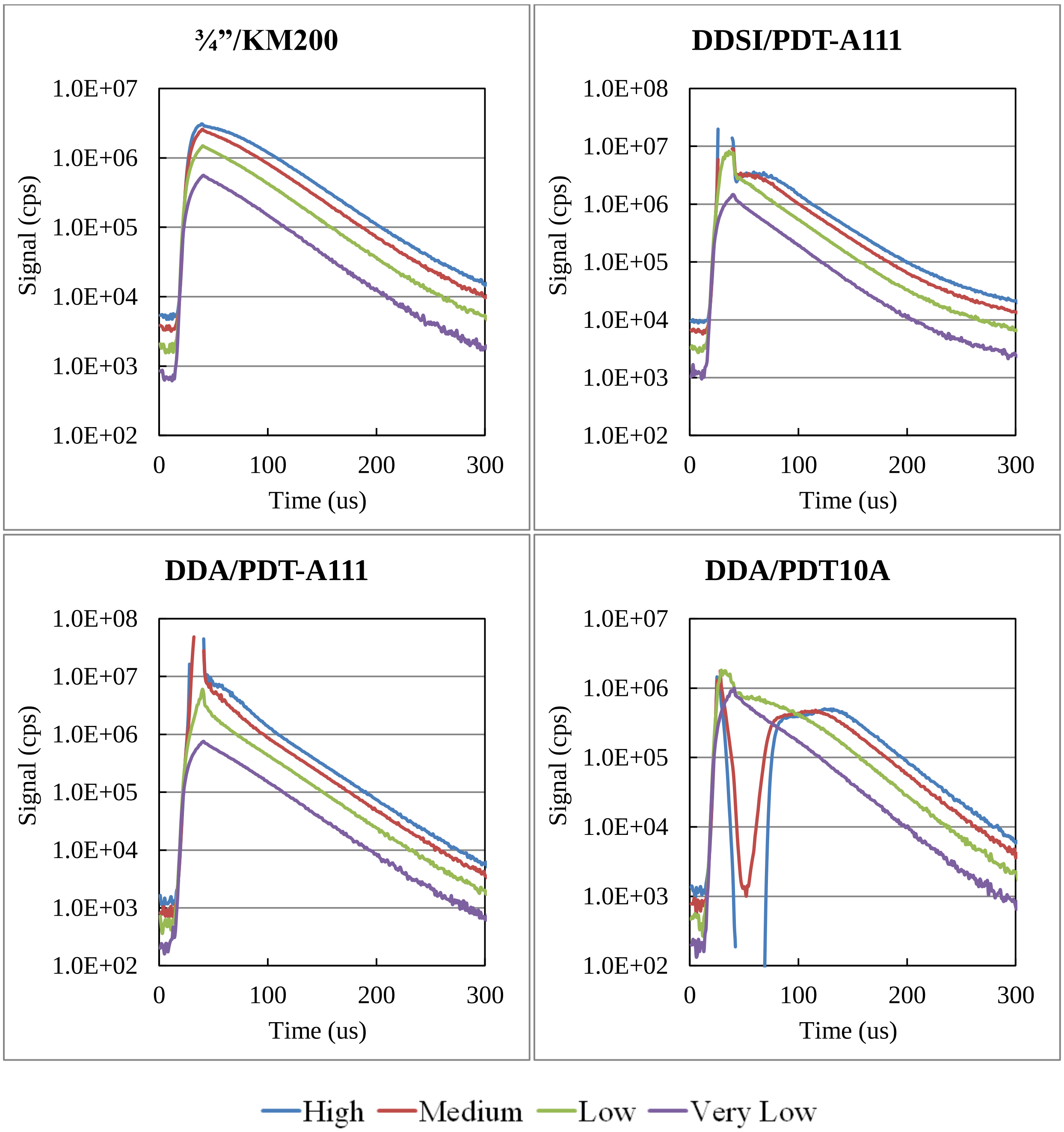

Figure 8. The deadtime corrected signals from the four detector/electronics packages at four DT neutron generator output settings.

Proposed Improvements

In the future we plan to test a dual channel ¾"/KM200 preamplifier. One channel operates as a standard preamp while the other channel only registers faster, higher amplitude pulses. Thus the fast channel further reduces deadtime effects and is less sensitive to gamma radiation.

We also plan to test the KM200 package paired with ½" diameter ^{3}He tube. This will potentially further decrease the deadtime effects.

We will continue to investigate the ^{3}He gas pressure and quench gas mixture most appropriate for the DDA instrument applications. Gamma sensitivity, stopping power, and other variables of interest will be considered before making a final decision for a universal DDA instrument.

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[3] K. Ianakiev, M. Swinhoe, M. Iliev and A. Goodsell, "New-Generation Thermal Neutron Detectors and Electronics for High-Count Rate Applications," LA-UR-14-23377, Los Alamos, 2014.

[4] K. Ianakiev, M. Iliev and M. Swinhoe, "High Count Rate Thermal Neutron Detectors and Electronics," IAEA-CN-220, 2014.