Self-calibration Method for Dead Time Losses in Neutron Counting Systems

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Abstract:

Most of the safeguards assay for quantitative characterization of SNM (mass, multiplication, random neutron contribution) are based on neutron measurements and rely exclusively on the counting information from very efficient, but slow He-3 proportional tubes. The response of neutron detection systems is inevitably affected by Dead Time (DT) losses that are generally caused by very complex and convoluted processes, which are difficult to take into account for corrections (for example, the DT losses for bipolar shapers differ from those of unipolar shapers). Therefore an empirical approach for calculating the DT losses assuming exponential (paralyzing) DT using measurements with two Cf-252 sources with known activities was established as current practice for many safeguards neutron counting systems. The availability of a very wide range of such Cf-252 calibration sources becomes the limiting factor for extending the deadtime correction calibration over a sufficient dynamic range to reach the conditions of real measured material.

In this paper we present a novel self-calibrating method for the determination and correction of deadtime losses that uses directly the neutron signal from real measured material. The count rate from the material is measured with two configurations of the preamplifiers: a standard configuration of the preamplifiers and tubes, corresponding to a nominal (100%) load per preamplifier and a second "deadtime measurement" configuration, where every two neighbouring clusters of He-3 tubes are connected together to a single preamplifier, corresponding to 200% load per preamplifier. A proof of principle DT calibration measurement over a wide dynamic range exceeding 10^6 reactions/sec using a 14 MeV neutron generator, demonstrated experimentally the viability of this method. The method produces the DT correction factor at every measured counting rate. The results show the very important observation that the correction factor does not fit with either fully paralyzing or fully non-paralyzing dead time models. Using either model could lead to substantial deadtime correction errors.

Explanation of DT behaviour and implementation aspects of this method in typical safeguards neutron systems (already in use or to be built) such as differential dieaway, coincidence and multiplicity counting will be discussed.

Keywords: neutron counting losses; dead time models; dead time correction; self-calibration; KM200

1. Introduction

The analytical measurements using pulse mode radiation detection systems rely on proportionality between incident and recorded radiation events. That proportionality is limited by the inevitable counting losses due to: a) random time distribution and intensity of the incident radiation events and b) the minimum response time of the detection system to process and record two separate detection events, called Dead Time (DT). The DT in a typical gamma spectroscopy measurement system has two components: a) one from the duration of shaped pulses resulting from convolution between the detector current pulse *I(t)* and time response (weighting function W(t)) of the selected pulse processing electronics and b) electronics time to detect the pulses above the event threshold, measure (typically the ADC measurement time) and record the amplitude of the pulse. Because the emphasis of gamma spectroscopy instrumentation is on preserving the energy information, unipolar shaping with time constant much longer than detector current pulse is used for better noise and ballistic deficit suppression. In order to correct these losses two DT loss models are conventionally applied: a) paralyzing DT model $N_{meas}=N_{in}*\exp(-N_{in}*t_d)$, where t_d is a deadtime constant used to correct the losses due to pile-up of superimposed unipolar pulses that prevents a new event being detected and recorded before the pile-up pulse goes below the event discriminator threshold and b) non-paralyzing DT model $N_{meas}=N_{in}/(1+N_{in}*t_d)$ used to correct the time for a pulse amplitude measurement process that is triggered by the event discriminator signal. These two models have similar behaviour at incident rate where DT losses are relatively low ($N_{in}* t_d << 1$) but very different behaviour at elevated rates and high DT losses [1, 2]. The uniform pulse shape due to time constants longer than the detector pulse and low busy time amplitude dependence due to very low event detection threshold (set just above the noise) provide a good match with constant extension of the DT of the paralyzing model. Therefore the paralyzing DT model combined with very effective pile-up

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rejection became an industry standard for correction of DT losses in gamma spectroscopy.

On the contrary, the emphasis in neutron counting systems is to preserve the counting information from the 3He detector despite the long (microseconds) and very fluctuating shape of the current pulse (see Fig 1a). Therefore with almost no exceptions the signal processing of existing electronics (Amptek-11, PDT, KM200) is based on bipolar shaping with time constant much shorter than the duration of the detector current pulse in order to reduce the dead time [3] as it is shown on Fig 1b.

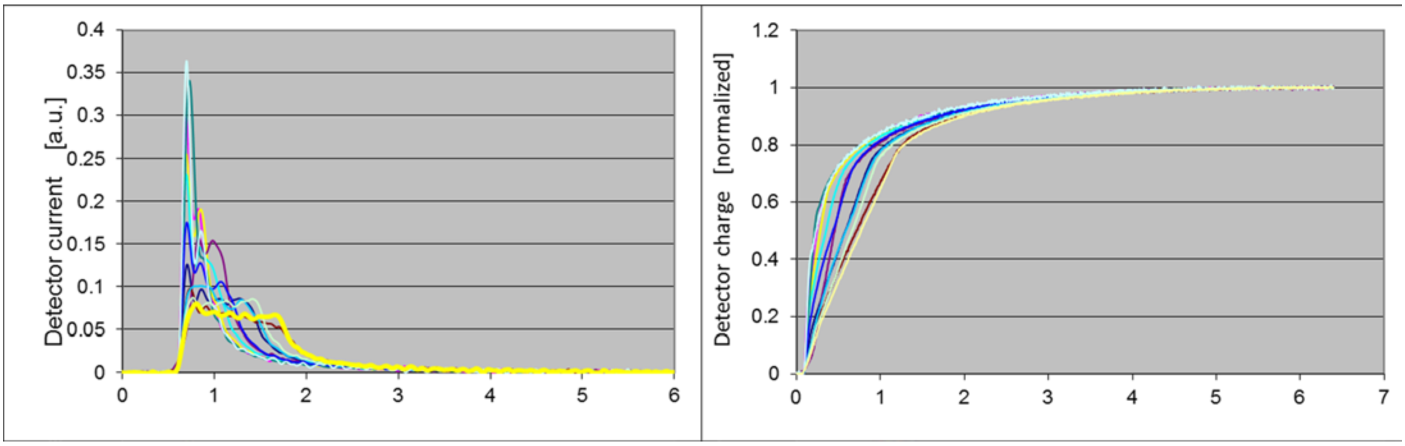


Fig. 1a: Normalized charge pulses (left) and corresponding current pulses. The fluctuation of charge collection time (left) result in very wide amplitude and duration of the current pulses (right)

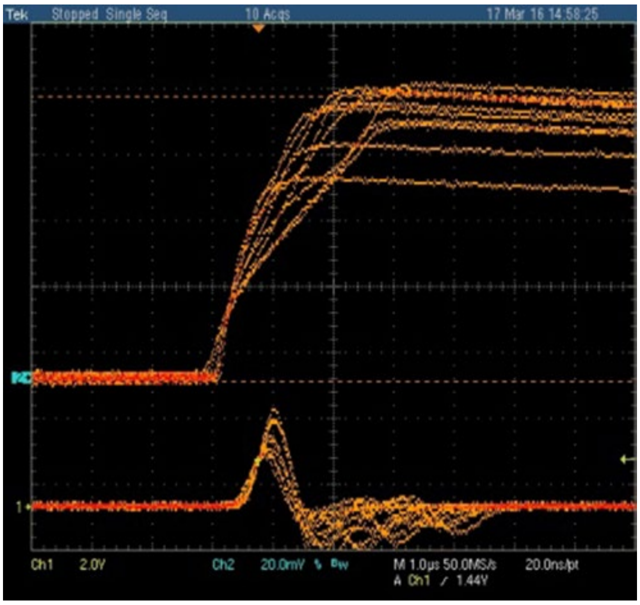


Fig.1b Charge pulses (top) of N2 gas fill He3 tube and corresponding bipolar output pulses from KM200-SLOW shaper [4]

The fluctuation of differentiated current pulses causes artificial parasitic triggering (the so called double pulsing effect). This effect is the main factor governing the selection of time constant as a trade-off between dead time and minimal amount of artificial pulses. We would like to stress that the average value of a bipolar pulse is zero (the areas of positive and negative lobes are equal). This leads to substantial differences in high count rate behaviour between unipolar and bipolar shapers:

- The pulse pile-up spectrum in a unipolar shaper is superimposed on the right (higher energy) versus the original spectrum while the pile up in the spectrum from a bipolar shaper is superimposed in both directions versus the original non-pileup spectrum.
- The pile-up of unipolar pulses causes updating dead time and is described very well with the exponential dependence of the paralyzing DT model (zero output at Nin* t_d >> 1). **Because the bipolar pulse has zero average value, the average value of superimposed bipolar pulses will be zero regardless of the input counting rate.** The intuitive implication is that the paralyzing DT model would not describe well the DT behavior of a bipolar shaper at elevated DT.

2. Description of the neutron detection system of the PUNITA facility and experimental setup

As described in the previous section, the DT losses in neutron counting systems are very complex and convoluted processes, which are difficult to take into account for corrections. Therefore an empirical approach for calculating the DT losses assuming exponential (paralyzing) DT using measurements with two ^{252}**Cf** sources with known activities was established as current practice for many safeguards neutron counting systems [5].

The following equations are used to calculate the dead time corrected singles (S_C) and doubles (D_C) rates:

$$S_C = S_M e^{\frac{\delta S_M}{4}} \quad (1)$$

$$D_C = D_M e^{\delta S_M} \quad (2)$$

where S_C and D_C are the true singles and doubles rates, S_M and D_M are the measured singles and doubles rates, respectively, and δ is the total deadtime coefficient given by:

$$\delta = \left(A + B \cdot S_M \cdot 10^{-6}\right) \mu s \quad (3)$$

where A and B are constants. The dead-time parameter B is approximated as $B = A^2/4$. These standard deadtime correction parameters (A and B) are applied to the singles and doubles rate for both coincidence and multiplicity analysis. The triples deadtime correction uses the multiplicity deadtime parameter. The multiplicity deadtime parameter was approximated as A/4.

It is important to note that there are several measurement methods that can be used to determine A and B for a particular detector system.

1. ***Doubles to Singles Ratio*** – measure the singles and doubles rates from at least 4 ^{252}Cf sources that span a large range in activity, plot ln(D/S) versus Singles rate, use a quadratic curve to fit the data and determine A.
2. ***Source Intensity Ratio*** – measure a strong and a weak ^{252}Cf source with very well-known neutron yields, set the ratio of the deadtime corrected doubles rates equal to the known ratio of ^{252}Cf yields, and iteratively solve the equation for A.
3. ***Paired Source*** – measure 2 high yield ^{252}Cf sources separately and then together, set the deadtime corrected doubles rate from measuring sources together equal to the sum of the deadtime corrected rates from measuring the sources separately, and iteratively solve the equation for A.

The system deadtime is affected by properties of the detector (e.g. polyethylene design, detector fill gas) and by the signal processing electronics (e.g. number of preamps, shaping time). The deadtime loss of neutron pulses increases at higher count rate, and it can be corrected empirically [6,7,8]. These techniques can provide excellent results for measurement samples with count rates in the range of the calibration sources used. But applications such as spent fuel, plutonium waste and MOX storage canisters, uranium and trans-uranium ingots, etc. often require operation at count rates many times the count rate of the empirical calibration. The reliance of the present deadtime calibration method on a single measurement point therefore introduces potential limitations, such as:

- It is difficult to find and measure ^{252}Cf sources in the entire dynamic range of the detection system.
- The count rates and neutron correlation characteristics of a ^{252}Cf calibration source are different from those of a measured SNM.
- And last but not least, the dead time behavior of bipolar shapers used in the ^{3}He electronics can differ from the calculated values based on the simple assumption of paralyzing DT model with a fixed deadtime constant even at low or moderate count rates.

3. Self-calibration method for counting loss correction

In order to address the challenges listed above, LANL has developed a new self-calibrating method for the determination and correction of dead time losses that uses the neutron signal from real measured material directly [9]. It is based on measuring the same incident reaction rate in the detector (count rate) from the material, N_{in}, with two configurations of preamplifiers: a standard configuration of preamplifiers and tubes, corresponding to a nominal (100%) count rate load per preamplifier and a second "dead time measurement" configuration, where every two neighbour clusters of detectors are connected together to a single preamplifier, corresponding to 200% load per preamplifier. An illustration of the described measurement is shown on Figure 2.

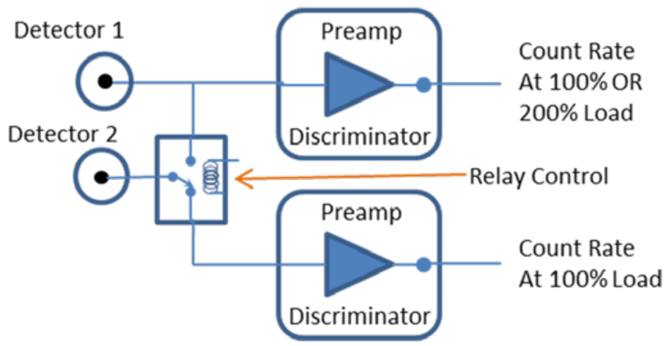


Figure 2: Illustration of detector switching method for dead time self-calibration. When the relay switch at the preamps' input is in its initial position, both channels see the normal count rate load ($N_{100\%}$). When the relay is switched, the bottom preamp sees no detector signal and the top sees the double count rate load ($N_{200\%}$). The TTL output of both preamplifiers are summed in OR circuitry.

The expression for the dead time constant (t_d) and the corrected input count rate per channel (N_{IN}) can be found using the following analysis:

First assuming the dead time in the system is paralyzing:

$$N_{100\%}\left(sum\ of\ two\ channels\right) = 2 \times N_{IN}\, e^{-N_{IN} t_d} \quad => \quad \frac{N_{100\%}}{2N_{IN}} = e^{-N_{IN} t_d} \qquad /4/$$

$$N_{200\%} = 2N_{IN}\, e^{-2N_{IN} t_d} \quad => \quad \frac{N_{200\%}}{2N_{IN}} = (e^{-N_{IN} t_d})^2 \qquad /5/$$

Where, $N_{100\%}$ is the measured count rate when one detector is connected to one amplifier, and $N_{200\%}$ is the measured count rate when two detectors are connected to one amplifier.

Observing that $e^{-N_{IN} t_d}$ is present in both expressions, we can eliminate the t_d unknown and simplify:

$$\frac{N_{200\%}}{2N_{IN}} = \left(\frac{N_{100\%}}{2N_{IN}}\right)^2$$

Solving for N_{IN}, we get an expression for the incoming count rate that involves only measured quantities:

$$N_{IN} = \frac{N_{100\%}{}^2}{2N_{200\%}} \qquad /6/$$

We can also solve for the value of the paralyzing dead time.

$$t_d = \frac{-2N_{200\%}}{N_{100\%}{}^2} \ln\left(\frac{N_{200\%}}{N_{100\%}}\right) \qquad /7/$$

Secondly we can apply the same method with the assumption of non-paralyzing dead time. In this case the measured count rates are:

$$N_{100\%} = N_{IN}\,(1 - N_{100\%}\, t_d) \text{ and } N_{200\%} = 2N_{IN}\,(1 - N_{200\%}\, t_d). \qquad /8/$$

Then, $\frac{N_{100\%}}{N_{200\%}} = \frac{1 - N_{100\%}\, t_d}{2(1 - N_{200\%}\, t_d)}$.

In the above equation t_d is the only unknown, so solving for t_d gives

$$t_d = \frac{2}{N_{200\%}} - \frac{1}{N_{100\%}}. \qquad /9/$$

Substituting t_d in the equation /5/ and solving N_{IN} for gives

$$N_{IN} = \frac{N_{100\%} N_{200\%}}{2(N_{200\%} - N_{100\%})}.$$

4. FNEM detector and DT calibration using classical dual source method

The classical paired source DT correction method was used to calibrate a new detector developed at KAERI called the Fast Neutron Energy Multiplication (FNEM) detector. This detector utilizes both FNEM and passive neutron albedo reactivity (PNAR) methods. FNEM consists of two rings of three ^{3}He tubes where 1 ring is located close to the sample cavity and the other ring is located far from the sample cavity (see Figure 3). The FNEM method is sensitive to the induced fission rate by fast neutrons and PNAR is sensitive to the induced fission rate by thermal neutrons. The total induced fission rate is proportional to the amount of fissile material in the sample being measured.

The efficiency for each ring of the FNEM detector was measured to be ~6.7% for the inner ring and ~0.75% for the outer ring. Since the FNEM method is based on multiplication (induced fission) in the measured sample, this detector was designed to measure high count rate samples (>1 x 10^6 n/s) and thus understanding the DT correction is essential to its calibration and characterization [10].

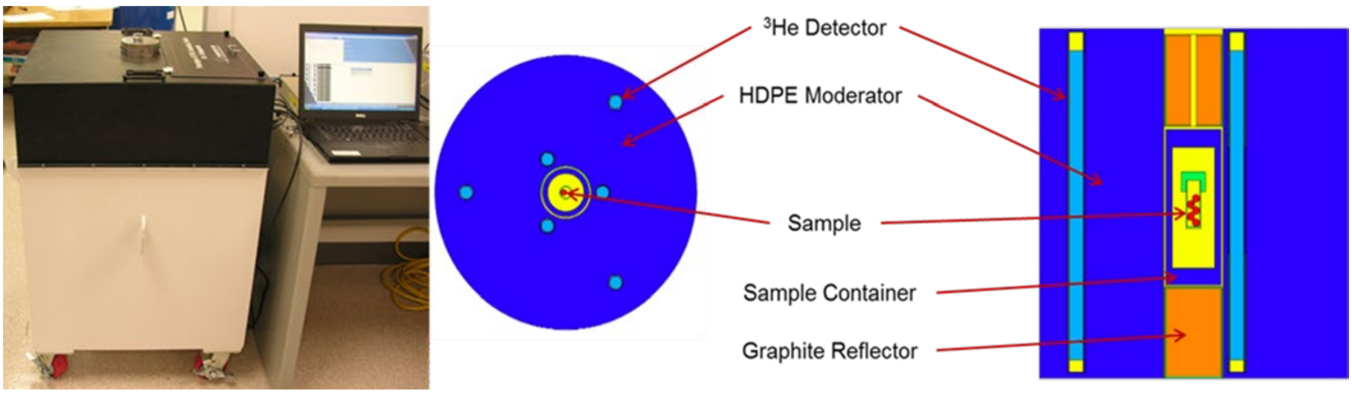


Figure 3: Picture and schematic of FNEM detector.

Using the paired source method described earlier in this paper, the DT coefficients (A and B) for FNEM were measured using two ^{252}Cf sources with intensities of 1.57×10^{6} n/s and 1.55×10^{6} n/s at LANL. The iteratively calculated coefficients for dead time were 2.147×10^{-6} for A and 1.152×10^{-12} for B, which were then applied in the INCC software. The fractional count loss of the inner ring was determined to be about 6.3% and 12.1% for the 0.12 and 0.25 MHz count rates, respectively [10]. It should be noted that the incident neutron rate used for deadtime measurement corresponds to about 3% of the maximum expected emission from a high count rate multiplying sample.

5. DT calibration using neutron generator and LANL self-calibration method

Because the exponential paralyzing DT model may not fit well the real behaviour of the bipolar shaper of PDT-110A , the extension of the calibration from two ^{252}Cf sources by a factor of 30 may lead to substantial count rate (respectively SNM mass) correction error. Therefore, we have used a neutron generator placed in the centre of the FNEM cavity as a neutron source with variable intensity of neutron flux. It should be noted that unlike the radioactive sources , we don't know the exact value of the NG neutron flux.

The neutron flux was controlled by changing the neutron generator's acceleration voltage and beam current, which provides a dynamic range greater than a factor of 10. Two types of measurements were performed: one with PDT-110A and another with KM200 electronics with a switching relay that allows us to measure $N_{100\%}$ and $N_{200\%}$. The KM200 electronics were mounted on an aluminium junction box that contains the HV and a switching relay circuitry. The preamps were gain matched and the plateau characteristics were tested in both switching configurations to make sure that the additional input-capacitance does not change the counting characteristics of KM200. This is possible because a) the gain of KM200 charge sensitive amplifiers does not change by small variations of input capacitance and b) the threshold is set at 40V above the plateau knee and thus can tolerate few tens of percent change of amplifier gain. We switched only the top two detectors (#1 and #3) in the first ring of the FNEM shown on Fig.4. During the first measurement, each detector was connected to its own preamplifier. We recorded the individual count rates to make sure that each detector sees roughly the same count rate. We used the average of the count rates of detector 1 and detector 3 to represent $N_{100\%}$. The second measurement was performed with detector #3 disconnected from preamplifier 3 and connected to preamplifier 1 which provided the count rate in DT measurement condition $N_{200\%}$.

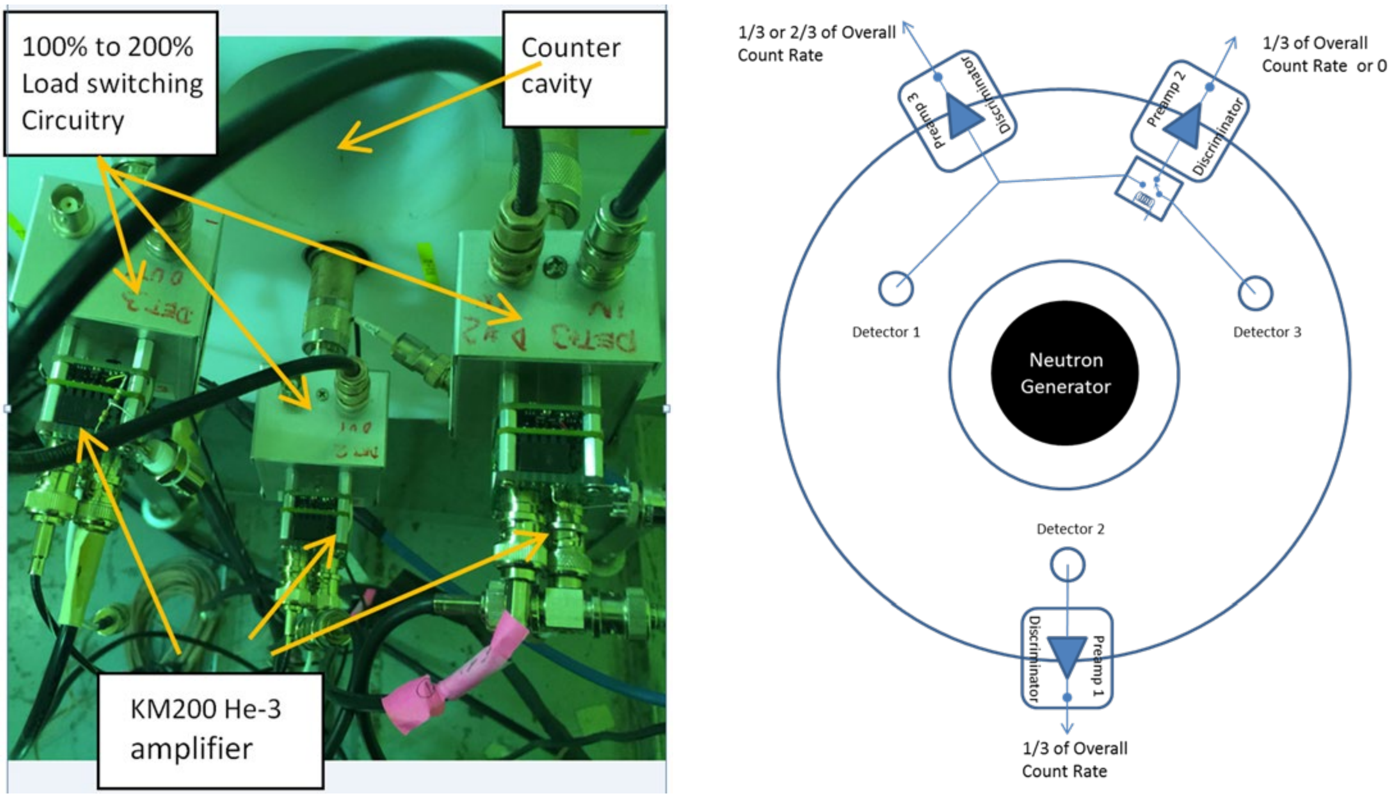


Fig. 4: Left: Top view of FNEM with preamplifiers and switching boxes installed on inner ring of tubes. Right: simplified switching diagram.

The count rates $N_{100\%}$ and $N_{200\%}$, corresponding to one and two tubes per amplifier, were measured for each intensity setting of the neutron generator. The load per amplifier and count rate data for each were recorded using a JSR-15 shift register. Using the analytical expressions derived in section two based on paralyzing dead time, we have calculated the incident neutron rate N_{IN} per amplifier. The measured count rates for PDT-110 (one tube per amplifier) and KM200 (one and two tubes per amplifier) are plotted in Fig 5.

The corrected output count rate Nout=Nin is used to calculate the dead time losses and corresponding dead time td based on the paralyzing DT model. In order to compare these results we also calculated and compared the KM200 and PDT-110A dead time using classical empirical and self-calibration methods for correction of counting losses. The plot on Fig.6 compares the calculated DT behaviour for:

- PDT-110A dead time from the paired source calibration in [10] calculated as 1.62 µs for 40 000 cps, and 1.54 µs for 83000 cps input count rate per tube;
- PDT-110A dead time using NG versus input count rate from self-calibration method ;
- KM200 dead time using NG and self-calibration method.

The results plotted in Figure 5 show significant dead time reduction (about 30%) between the calibrated and extended range of count rates as well as good consistency in PDT dead time behaviour using paired ^{252}Cf source and NG. The deduced dead time constant (t_d) shows a reduction in value for higher count rates. This is a clear indication that the real dead time losses do not follow the exponential dependency of the paralyzing DT model. The correction of counting losses using equations /6,7/ for non-paralyzing DT model provided even higher dead time constant dependence with positive slope. Therefore we used the correction data based on paralyzing DT that has lower dead time deviation at the maximal count rate range and thus fits better for that particular case.

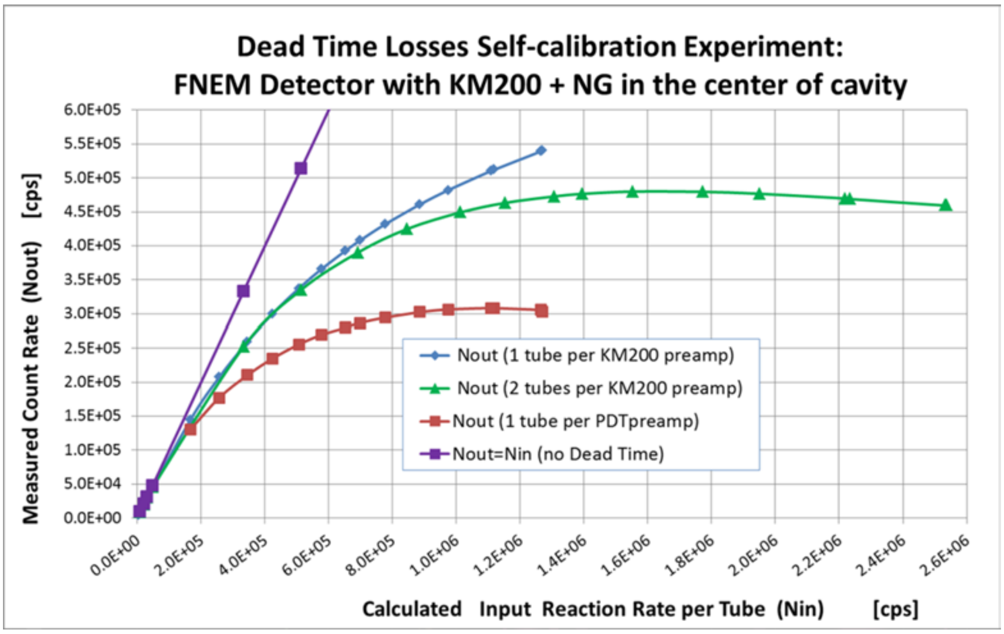


Figure 5: Measured count rates per amplifier versus (determined) input count rates for the KM200 at $N_{100\%}$ (blue) condition, KM200 at $N_{200\%}$ condition (green) and PDT110A amplifier (red) connected to one detector. The purple line represents the count rate (Nout=Nin).

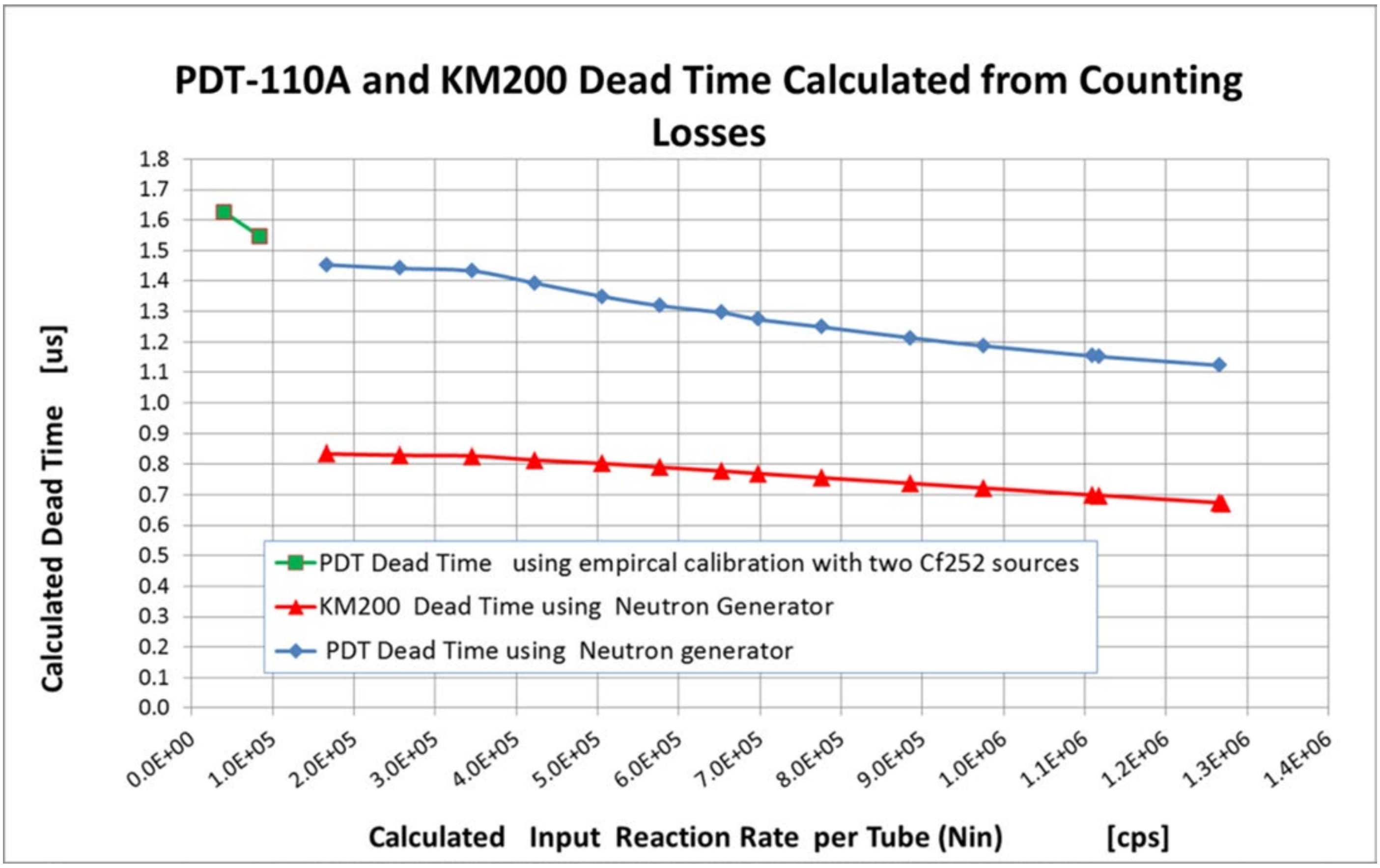
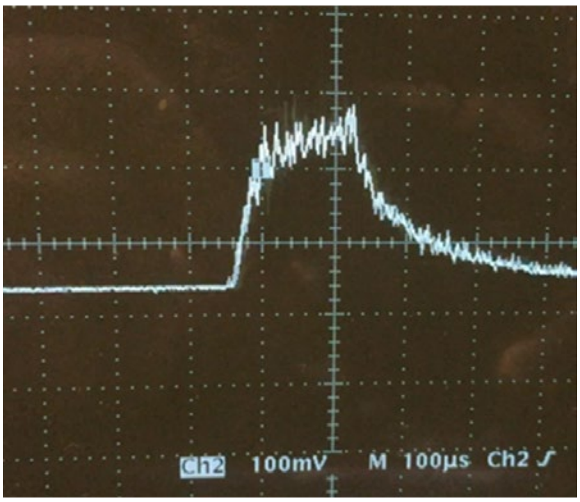


Figure 6: DT versus input count rate. Green: PDT-110A DT using a pair of ^{252}Cf sources [10]. Blue: PDT-110A DT using a NG and empirical method for correction of counting losses. Red: KM200 dead time using NG and self-calibration method for correction.

It should be noted that neither the non-paralyzing nor the paralyzing models are accurate over a wide dynamic range of incoming neutron count rate. Therefore, it is necessary to perform dead time calibration near the intensities of the target measured source. This is where the proposed calibration method is most valuable. It does not rely on the extrapolation of a priori calibration at lower intensity.

In order to explore and explain the count loss trend at higher count rates we ran the neutron generator in pulsed mode where the constant output emission rate is increased in reverse proportion to the generator duty cycle. The snapshots of the unipolar (current pulse) and bipolar (shaper output) signals from KM200 amplifiers, recorded at 10% duty cycle and maximum intensity of the neutron generator are shown on Fig. 7. The estimated incident rates for that setting is about 13×10^6 cps (10 times higher than maximum count rate from continuous output testing shown on fig.5.



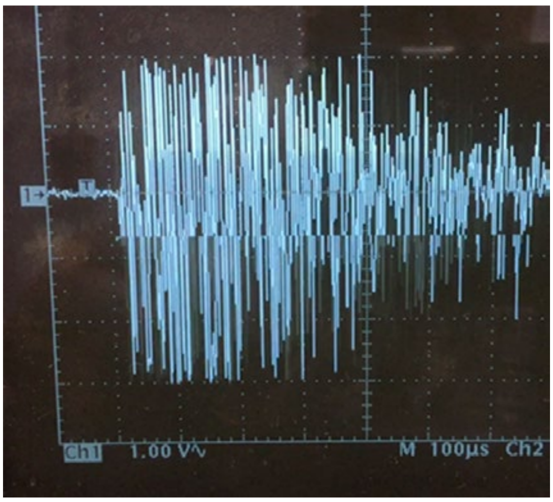


Fig. 7 Left: unipolar (current pulses) Right: The bipolar pulse output

The pile up of detector current pulses appears as a single fluctuating pulse that does not reach the base line during the entire duration of the neutron generator pulse, consistent with the updating paralyzing dead time model. In contrast, the bipolar pulses pile-up in both directions and thus cross the baseline despite the severe pile-up (20+ pulses during the duration of shaper pulse) and thus continue to count. Because of the random phase of the pile-up the superimposed signal looks much wider than singe bipolar pulses shown on Fig.1b.

6. Implementation aspects of this method in typical safeguards neutron systems

6.1 Active interrogation

Fission neutron detectors used in the pulsed active interrogation systems such as DDA assay for measuring of SNM have to operate at very wide dynamic range of incident count rates and thus are subject of severe counting losses. Implementation of faster tubes and electronics can improve the counting capabilities and allow analysis closer to the burst, but will not eliminate all of the counting losses. The implementation of this self-calibration method could further expand this capability by using simple switching circuitry without extensive retrofitting of existing electronics. The DT losses can be characterized by one time calibration that can give values that can be used for routine measurements. Because the DDA assay relies on singles rate measurements, DT losses are smaller and the accuracy of the calibration is not as critical as for assays based on neutron coincidence counting. Initial testing of this method in JRC PUNITA active interrogation system at JRC-Ispra will be reported in [11].

6.2 Neutron coincidence counting

Unlike singles rate measurements, neutron coincidence counting is very sensitive to the counting losses as the DT losses error of singles propagates with power 2, 3 etc., to the double, triples moments. The currently used DT loss calibration works well for low DT losses where the paralyzing DT model does not deviate much from the experimentally observed behaviour of the DT losses. But an applications such as coincidence assay for measuring high mass plutonium canisters, spent fuel, etc, that are expected to operate at higher DT losses the current practice for calibration with low activity ^{252}Cf sources may lead to substantial errors.

Here the measured count rates (S,D,T etc.) for the two hardware configurations (standard – i.e. 100% load and dead time – i.e. 200% load) can be used to extract and correct for dead time losses. Two possible methodologies are envisioned: a) extrapolate dead time free count rates from the slope of the measured count rates for 100% and 200% load; b) iterative procedure to extract and correct for dead time losses. The former approach relies on linearity of the count rate variation with preamplifier load, which will be explored and confirmed experimentally. For more complex situations, where nonlinearities in count rate variation with preamplifier load are observed, the iterative approach will be used. The iterative approach is foreseen to use the ratios (e.g. $\frac{S_{100\%}}{S_{200\%}}; \frac{D_{100\%}}{D_{200\%}} \frac{T_{100\%}}{T_{200\%}} \frac{Q_{100\%}}{Q_{200\%}}$) for singles, doubles, triples and quads, that, if properly dead time corrected, should not depend on the load per preamplifier. We will use this fact to develop the iterative calibration procedure, where the initial estimate of dead time correction will be used to extract initial dead time corrected count rate ratios for both preamplifier loads. The dead time correction estimate will then be further iterated until close agreement between the dead time corrected ratios for 100% load and 200% load measurements is achieved.

We would like to stress that the proposed method and hardware implementation is applicable for all currently used preamplifiers (such as Amptek A-111) electronics for both shift register and list mode data acquisition.

7. Conclusion

We have presented a new hardware based method for the determination of counter dead time. This method can use the counting rates from actual unknown samples in order to determine the dead time correction constants and thus avoid the problem of extrapolating dead time coefficients determined at low counting rates to high counting rates. The hardware is relatively easy to retrofit to many existing neutron detectors. We have demonstrated the method for singles counting and shown that the dead time behaviour of typical neutron detector systems does not follow either paralyzing or non-paralyzing model precisely, but the paralyzing model is closer. The method can also be used for doubles and triples and higher moments of multiplicity counters.

8. Acknowledgments

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9. References

[1] G. F. Knoll. “Radiation Detection and Instrumentation” – 3rd ed., New York, NY: Wiely & Sons, 2010

[2] R. Jenkins, R. W. Gould, D. Gedcke. “Quantitative X-rays Spectroscopy”, New York, NY: Marcel Dekker, Inc., 1995

[3] K. Ianakiev, M. Iliev, M. Swinhoe and N. Johnson “High Count Rate Thermal Neutron Detectors “High

Count Rate Thermal Neutron Detectors "IAEA Safeguards Symposium, Vienna, 2014

[4] Iliev, Metodi; Ianakiev, Kiril Dimitrov, Swinhoe, Martyn Thomas "KM200 Front-End Electronics for Thermal Neutron Detectors", INMM 57th Annual Meeting, 2016-07-24/2016-07-28 (Atlanta, Georgia, United States)

[5] N. Ensslin, W. C. Harker, M. S. Krick, D. G. Langner, M. M. Pickrell, J. E. Stewart, "Application Guide to Neutron Multiplicity Counting," LANL, Los Alamos, NM, LA-13422-M, November 1998.

[6] H.O. Menlove, M.T. Swinhoe, J.B. Marlow, et al., "Mini-Epithermal Neutron Multiplicity Counter (Mini-ENMC) Manual," Los Alamos National Laboratory Report, LA-14350-M (2007).

[7] L. Holzleitner, M.T. Swinhoe, "Dead-time correction for any multiplicity using list mode neutron multiplicity counters: A new approach – Low and medium countrates," Radiation Measurements 46 (2011) 340-356.

[8] A. M. LaFleur, et al. "Characterization and performance evaluation of a new passive neutron albedo reactivity counter for safeguards measurements", Radiation Measurements 61 (2014) 83-93.

[9] K. Ianakiev, M. Iliev, M. Swinhoe, HIGH COUNT RATE THERMAL NEUTRON DETECTORS AND ELECTRONICS; Provisional Patent Application Serial No. 62/411,898;

[10] Hee Seo, et al. "Development of prototype induced-fission-based Pu accountancy instrument for safeguards applications", Applied Radiation and Isotopes Volume 115, September 2016, Pages 67–73

[11] K. D. Ianakiev[1], M. L. Iliev[1], M. T. Swinhoe[1], B. Pedersen[2], G. Varasano[2], J. Crochemore[2], T. Bugucarska[2], L. Holzlightner[2], P. De Baere[3,] S. Vaccaro[3], M. Couland[4,] « Field trial of KM200 Electronics in the JRC PUNITA Facility" , 39th ESARDA Conference, 15th-18th May 2017, Dusseldorf, Germany