

# Improved electronics for $^3\text{He}$ based neutron counters

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**Abstract**— Several non-destructive assays techniques have been developed for the measurement of fissile materials in the fields of dismantling, decommissioning, nuclear security, and nuclear safeguards. Among these techniques, neutron coincidence counting is based on the detection of time-correlated neutrons from induced and spontaneous fissions.  $^3\text{He}$  Tubes have been the primary choice for neutron coincidence counting due to their high detection efficiency, rather low sensitivity to gamma-rays and proven field reliability. This paper covers the implementation of a new electronic setup to a Canberra WM3400 neutron coincidence counter.

First we describe the properties of the used detectors, with focus on the characteristics of the default electronics and highlight its limitations such as the high input capacitance, short shaping time and the necessity for selected tubes. We then propose the new electronic setup to overcome these limitations. This setup includes a dedicated preamp for every tube, the possibility to adjust for gain differences between the tubes and a better optimised shaping time for  $^3\text{He}$  detectors.

We carried out measurements with the two electronic systems to compare their performances in terms of gamma-ray sensitivity, efficiency and die-away time. The gamma ray sensitivity was measured with calibrated  $^{137}\text{Cs}$  and a  $^{60}\text{Co}$  sources at the Laboratory for Nuclear Calibration of the Belgian Nuclear Research Centre with dose rates between  $10\ \mu\text{Sv/h}$  and  $50\ \text{mSv/h}$ . Measurements with a  $^{252}\text{Cf}$  source were used to determine the die-away time of the system and the total measurement efficiency for the considered geometry.

The measurements showed that, with the default electronics, neutron count-rates are already affected by gamma radiation at a dose rate of  $10\text{--}30\ \mu\text{Sv/h}$ . On the other hand the neutron coincidence counter equipped with the new electronics proved to be insensitive to gamma-radiation up to a dose rate of at least  $20\ \text{mSv/h}$ . The high-voltage set with the new electronics is lower than in the case of the default electronics and is within the range recommended by the tubes manufacturer. The die-away time was not affected by the used electronics. A reduction of about 20% in the neutron detection efficiency due to the used discriminator threshold was observed.

**Index Terms**—  $^3\text{He}$  counters, Electronics, Neutron coincidence counting, Non destructive assay

## I. INTRODUCTION

Several non-destructive assays (NDA) have been developed for the measurement of fissile materials in the fields of dismantling, decommissioning, nuclear security, and nuclear

safeguards. Among the NDA techniques, neutron coincidence counting (NCC) is based on the detection of time-correlated neutrons from induced and spontaneous fissions [1]. Tubes filled with  $^3\text{He}$  gas have been the primary choice for NCC due to their high detection efficiency, typically low sensitivity to  $\gamma$ -rays, and proven in-field reliability [2].

This paper covers the implementation of a new electronic system to the Canberra WM3400 neutron coincidence counter [3]. We describe the characteristics of the detectors used, with focus on the default electronics and the new system. We carried out measurements with the two electronic systems to compare the performance in terms of gamma-ray sensitivity, efficiency and die-away time. The conclusions from the comparison and the plans for future work are included at the end of paper.

## II. WM3400 NEUTRON COINCIDENCE COUNTERS

Two used Canberra WM3400 neutron coincidence counters as well as two Canberra JSR-12 shift registers [4] for the data acquisition and analysis were acquired recently by SCK-CEN in the context of disposal of irradiated material containing small amounts of fissile material. Each detector has six  $^3\text{He}$  tubes with 2.54 cm diameter and active length of 91.44 cm; the  $^3\text{He}$  tubes are aligned in a single row and the  $^3\text{He}$  tubes are embedded in polyethylene to ensure neutron moderation. The moderator is enclosed in an aluminium cover, and a 1-mm layer of Cd is applied to five sides of the moderator below the aluminium cover. Only the side facing the radioactive source is not covered by Cd.

### A. Default Electronics

In the default electronics, all six  $^3\text{He}$  tubes are connected in parallel in order to facilitate the distribution of the high voltage. The output signal of the tubes is capacitive coupled to a JAB-01 Amptek board. This board is equipped with an Amptek A111 hybrid preamplifier-discriminator with its threshold adjusted to minimize the gamma sensitivity [5] and some driver-logic. The output-signal is a 50 ns wide TTL signal which can be used for data acquisition e.g. with a neutron coincidence analyser such as the JSR-12 shift register [6] or the MCA-527 with time stamp processing firmware [7]. Both systems can provide the high voltage (HV) for the detectors and the +5V for the JAB-01.

The first problem with this configuration is the strong increase in input capacitance due to the fact that all the tubes

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are mounted together. This setup increases the input capacitance, reduces the signal/noise ratio and makes the preamplifier more prone to oscillations.

A second problem is related to the shaping time. The shaping time of the Amptek A111 is only 0.15  $\mu$ s which is adequate for high count rates but results in a non-optimal separation of neutron and gamma signals. To overcome the consequent lack of gain, the manufacturer decided to operate the tubes well beyond their specification. While the normal high voltage operating range according to the manufacturer of the tubes is 1000  $\div$  1250 V, the recommended value in [5] is 1700 V. This fact further worsens the discrimination between neutron and gamma signals.

Finally, because there is no option to adjust the gain of the individual tubes, they were selected to match their responses at the same high voltage.

To address all these issues and to operate the tubes at a lower high voltage, we decided to develop new dedicated electronics.

### B. New Electronics

In the new electronics the signal processing is split into a preamp unit and a processing unit as shown in Fig. 1. In the preamp unit each tube is equipped with its own preamp in a charge amplifier configuration. This setup reduces the input capacitance for each preamp giving a better signal to noise ratio and allowing to calculate the proper feedback capacitance/resistor to ensure enough phase-margin for stability. It also makes it easier to see if one of the tubes fails.

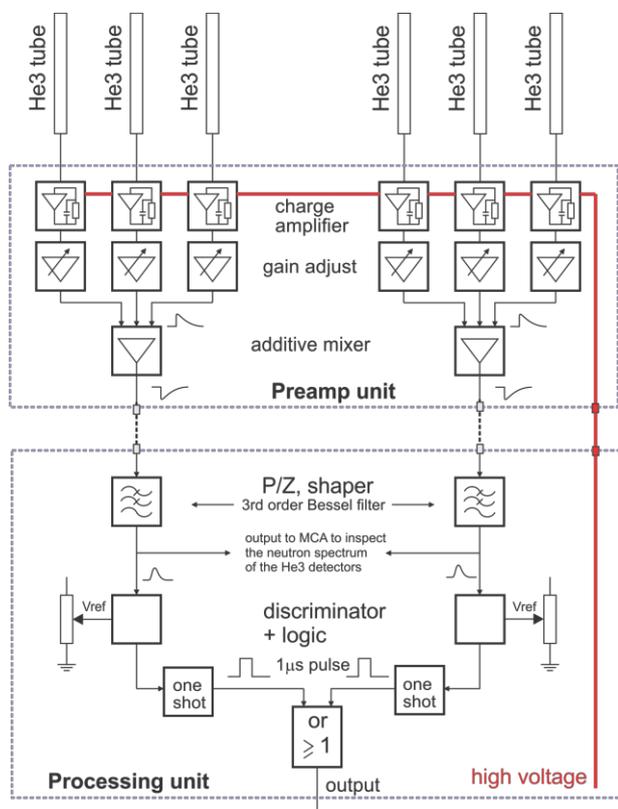


Fig. 1. Diagram of the new electronics.

The next step is an adjustable non-inverting amplifier. The resulting analogue output signals of three tubes are added together in the additive mixer. Adding the signals of three tubes allows to reduce the number of cables to the processing unit and the number of shapers. Adding more tubes together would increase the risk of pile-up. The resulting signals are then sent to a 3<sup>rd</sup> order Bessel filter (150 kHz) indicated as P/Z shaper in the processing unit.

The gains are adjusted so that all tubes have the same output-level. This setting is verified by measuring the signal with a Multi-Channel Analyser (MCA) just after the shaper. All tubes are adjusted so that the thermal peak of the <sup>3</sup>He spectrum ends up in the same channel. By doing so, we have just one discrimination level for all tubes and there is no need to use specially selected tubes anymore.

A measured energy deposition spectrum with a <sup>252</sup>Cf source is shown in Fig. 2. The peak at 765 keV corresponds to the energy deposition of tritons and protons following (n,p) reaction on <sup>3</sup>He. Noise and gamma signals are present in the low energy part of the spectrum.

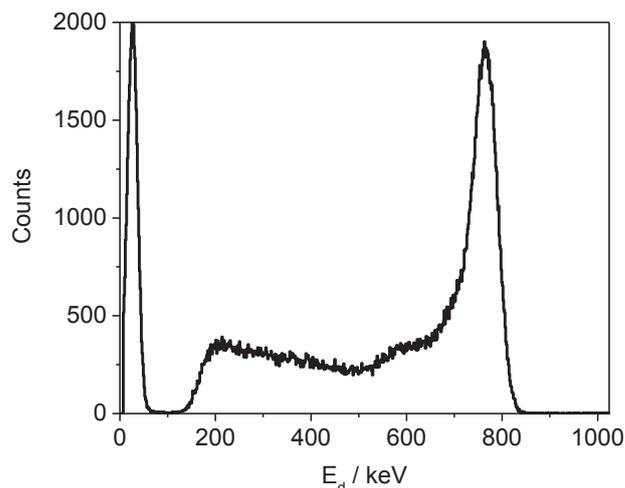


Fig. 2. Measured energy deposition spectrum. E<sub>d</sub> stands for deposited energy.

The discrimination, as shown in Fig. 3, is done in the processing unit which is physically far away from the preamps in order to reduce crosstalk between them. The discriminator value should be set such that all events below a deposited energy of approximately 191 keV are rejected. This value corresponds to the minimum energy typically observed in the energy deposition spectrum and corresponds to the energy deposition of triton following (n,p) reaction on <sup>3</sup>He. By setting the discrimination threshold at 191 keV all neutrons interacting by (n,p) reaction on <sup>3</sup>He are detected. Adjusting the discriminator level is done by using an MCA. By delaying the signal and gating it with the output pulse of the discriminator we can visualise the effect of the adjustment. The output of the discriminator is fed to a non retriggerable one shot. As shown in Fig. 1, both channels are OR-ed and the output can go to the shift register. The high voltage is reduced to +1350 Volt, which is closer to the nominal operating range recommended by the

tubes manufacturer. At this voltage we observed a change in gain of 10% when the high voltage is changed by 10 Volt; therefore, it is important to use a high voltage supply unit with sufficient stability.

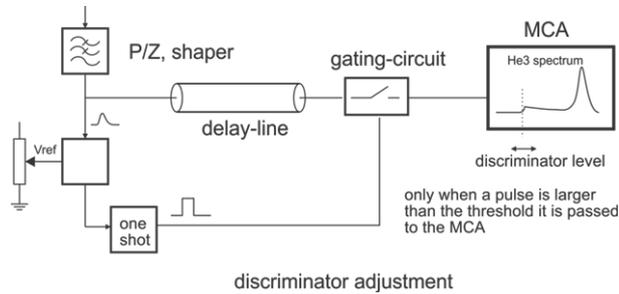


Fig. 3. Adjustment of the discriminator threshold.

### III. MEASUREMENTS

We measured the gamma sensitivity with calibrated  $^{137}\text{Cs}$  and  $^{60}\text{Co}$  sources at the Laboratory for Nuclear Calibration of SCK•CEN [8] with dose rates between  $10 \mu\text{Sv/h}$  and  $50 \text{mSv/h}$ . We recorded the total neutron counts as well as the number of counts in the R+A and A gate as a function of the dose rate. All measurements at different dose rates were carried out with and without a  $^{252}\text{Cf}$  source (37 kBq on 15 August 2015) positioned in front of the detector in a fixed geometry. Background measurements were also carried out. Most of the measurements lasted for 600 s.

In addition, measurements with the  $^{252}\text{Cf}$  were used to determine the die-away time of the system and the total measurement efficiency for the considered geometry. The considered geometry consisted in positioning the source and geometrical centre of the front face of the WM3400 counter.

Both the new and the default electronics were tested with the JSR-12 and the MCA527.

### IV. RESULTS

The neutron count rate and reals rate in absence of an external gamma source were taken as a reference. The change in the total neutron count rate without  $^{252}\text{Cf}$  source as a function of the dose rate for the system with the default and new electronics are shown in Fig. 4. The variation in reals rate with the  $^{252}\text{Cf}$  source, defined as the difference between the counts in R+A gate and in the A gate divided by the measurement time, as function of the dose rate is shown in Fig. 5. In the absence of an external gamma source, the total count rate without  $^{252}\text{Cf}$  source was  $1.5 \pm 0.1$  cps, while the reals rate with the  $^{252}\text{Cf}$  source was  $9.6 \pm 0.5$  cps.

For the default electronics, the gamma sensitivity data indicate that the neutron counts are affected already at a gamma dose rate of  $10 \div 30 \mu\text{Sv/h}$ . The reals rate is almost not affected up to a dose rate of about  $1 \text{mSv/h}$  although a bias seems to be present.

With the new electronics the neutron count rate is unaffected by gamma radiation up to  $20 \text{mSv/h}$  and the maximum available dose rate of  $50 \text{mSv/h}$  was not sufficient to change the reals rate.

The results of these measurements provide confidence in our interpretation of the limitations of the default electronics.

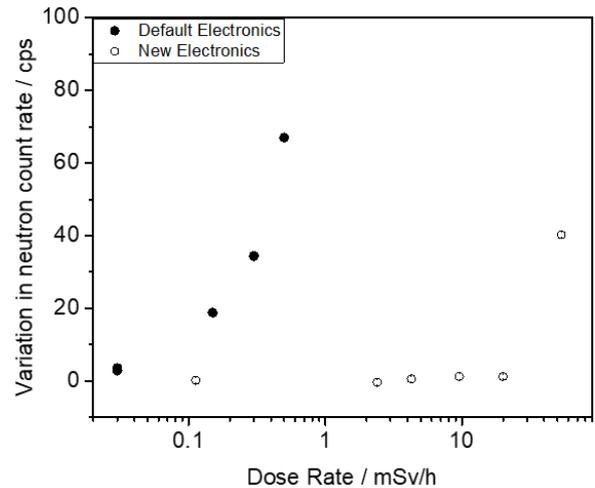


Fig. 4. Change in the total neutron count rate without  $^{252}\text{Cf}$  source as a function of the dose for the system with the default and new electronics.

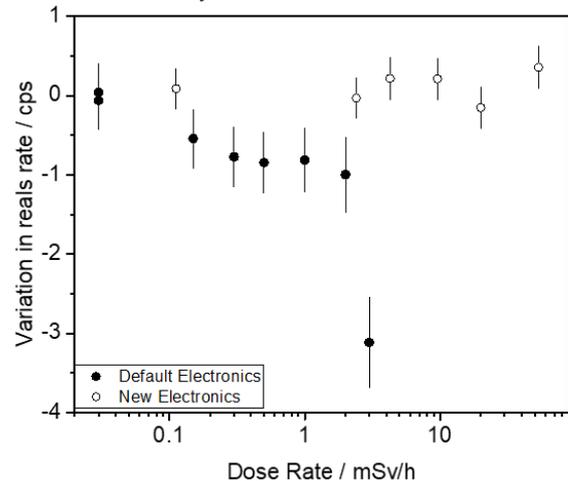


Fig. 5. Change in the reals count rate without  $^{252}\text{Cf}$  source as a function of the dose for the system with the default and new electronics.

The total count rate and reals rate with a  $^{252}\text{Cf}$  source can be used to determine the efficiency and the absolute source strength at the time of the measurement by applying the point model equation given in [10]. For the default electronics, we obtained an efficiency of  $6.6\% \pm 0.1\%$ . We used the nuclear data given in [11]. The die-away was obtained by applying Eq. 16-16 of Ref. [1] and the obtained value was  $57.1 \pm 0.1 \mu\text{s}$ . The source strength was about  $2150 \text{n/s}$ , consistent with the declared activity after accounting for its decay.

For the new electronics, the obtained source strength was in agreement with the results of the default electronics when taking into account the decay of the source. The obtained values for the efficiency and die away are respectively  $5.1\% \pm 0.1\%$  and  $57.6 \pm 0.1 \mu\text{s}$ . While the die-away time is consistent with the one obtained with the default electronics, the efficiency is about 20% lower. Further investigations revealed that the discrimination threshold was set higher than the desired value of  $191 \text{keV}$ .

## V. CONCLUSIONS

This work focussed on an improved electronics for a  $^3\text{He}$  neutron coincidence counter. The performance in terms of gamma-ray sensitivity, die-away time and efficiency were determined for a WM3400 neutron coincidence counter with a default and with a new signal processing electronics. The obtained results indicate that the neutron coincidence counter is insensitive to gamma-radiation up to a dose rate of at least 20 mSv/h. Due to the used value of the discrimination threshold a reduction of about 20% in the neutron detection efficiency was observed..

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