Intrinsic background of the neutron detectors of the NEMUS spectrometer

For measurements in low-intensity neutron fields, it is absolutely indispensable to know the intrinsic background of detectors. During a two-month measurement campaign, all ^{3}He detectors of the NEMUS neutron spectrometer were investigated in the underground laboratory of PTB (UDO) and their lower detection limit was determined.

For measurements in low-intensity neutron fields (e.g., to determine the neutron source strength of a ^{228}Th gamma test source for the BOREXINO Experiment [1]), it is absolutely indispensable to know the intrinsic background of detectors. During a two-month measurement campaign, all ^{3}He detectors of the NEMUS neutron spectrometer [2] were investigated in the underground laboratory of PTB (UDO) [3] and their lower detection limit was determined.

At the centre of each single sphere of the NEMUS spectrometer is a spherical proportional counter filled with ^{3}He gas (of type SP9, Centronic Ltd., UK) which is used to detect thermal neutrons. Due to impurities (α-emitters) in the materials used, such detectors have an inherent background as shown in a previous investigation [4]. If the number of incident neutrons per surface and per time (neutron flux density) of the radiation field to be measured is small (e.g. in the case of neutrons from cosmic radiation at sea level < 40 cm^{-2} h^{-1}), the contribution of the intrinsic background is no longer negligible. To be able to determine the intrinsic background, which consists of signals from alpha-particles emitted in the counter and, additionally, of electronic noise, it is necessary to "switch off" – as far as possible – incident neutron radiation from the outside. This is only possible in special underground laboratories, such as PTB's former UDO laboratory.

In a series of complex measurements, all currently available ^{3}He detectors of the NEMUS spectrometer were tested with the electronic measuring system presently used. Figure 1 shows the test arrangement with 8 detectors running in parallel which were positioned in a low-vibration set-up in front of the electronic modules, vertically standing.

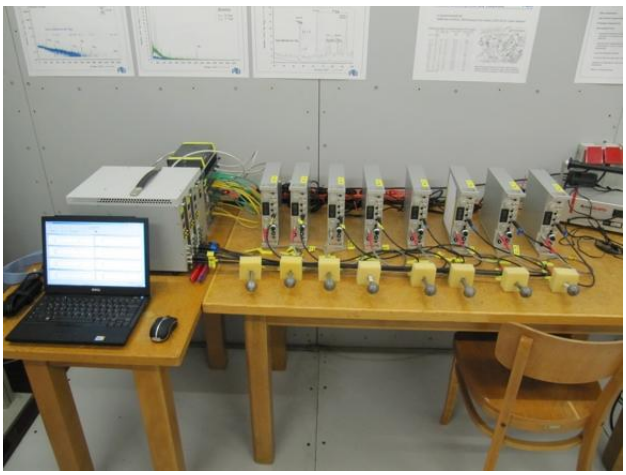

Fig. 1: Test set-up with eight ^{3}He proportional counters running in parallel. On the table (left), further data-acquisition modules are visible behind the notebook with the data-acquisition software.

The measurement result for each detector is a pulse-height spectrum (PHS) in the following form: number of events *N* (within a certain time) as a function of the channel number *k*. The channel number corresponds to a certain amplitude of the signal inside the detector and, thus, to an energy deposited in the detector. Figure 2 shows two examples of pulse-height spectra, as they are typically measured with the SP9 counters in the presence of external neutron radiation. A PHS with a high count rate is shown on the left; it is caused by a high neutron flux density. The PHS on the right was measured in a low-neutron radiation environment.

When thermal neutrons are captured in the ^{3}He gas, a reaction energy of 764 keV (Q-value of the ^{3}He(n,p)t reaction) is released; during this process, due to the conservation of momentum, a proton with an energy of 573 keV and a triton with an energy of 191 keV are emitted in the centre-of-mass with an angle of 180°. Under ideal circumstances, the total reaction energy is deposited in the counter gas, which can be recognized by the distinct maximum in the pulse-height distribution. Wall and border effects, however, cause part of the kinetic energy of the secondary particles to be deposited in the wall of the counting tube and, thus, not to contribute to the ionization in the gas. The pulses, which are generated by neutrons and, thus, determine the measuring quantity of a given sphere of the spectrometer, lie on the right of a given channel number (threshold) corresponding to an energy of 191 keV. The events located left from this threshold correspond to signals from gamma particles and electronic noise.

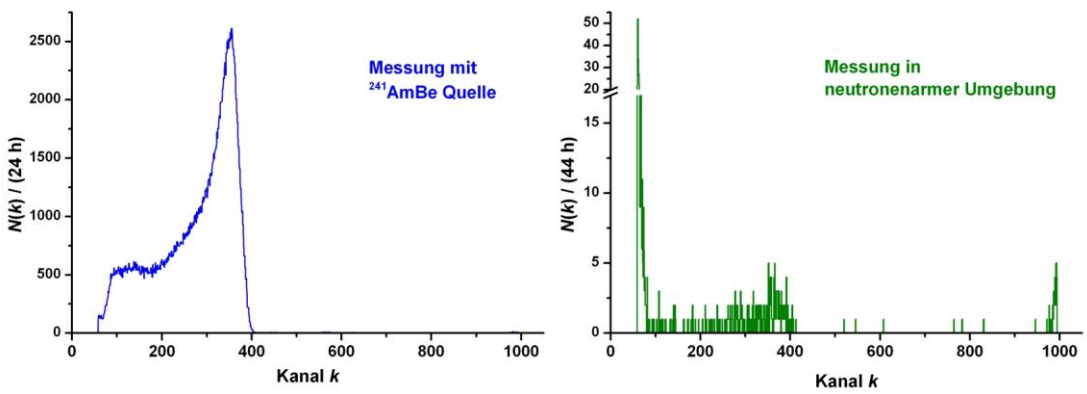

Fig. 2: Pulse-height spectra of SP9 counters in the presence of external neutron radiation with high count rates caused by a high neutron flux density (left) or in a low-neutron radiation environment (right).

In pulse-height spectra measured at PTB's former underground laboratory UDO [3], there should be no neutron events due to the absence of external neutron radiation. The lower diagram of Figure 3 shows a typical PHS as recorded at the UDO laboratory. The events left from channel 90 are electronic noise and, in the interval from channel 90 to channel 890, rare events can be seen which, at first sight, seem to be equally distributed. Due to this low number of events, it is convenient to switch to the integral representation I of the PHS as a function of the channel number *k*: $I(k) = \sum_{i=1}^{k} N(i)$ where $N(i)$ is the channel content of the pulse-height spectrum *N* , see upper diagram of Fig. 3. In this diagram, only the signals above the threshold for

electronic noise are shown, i.e. in this example, summation begins at channel 90 only. These signals originate from alpha-particles which have been emitted by contaminants in the materials used for the production of the detector.

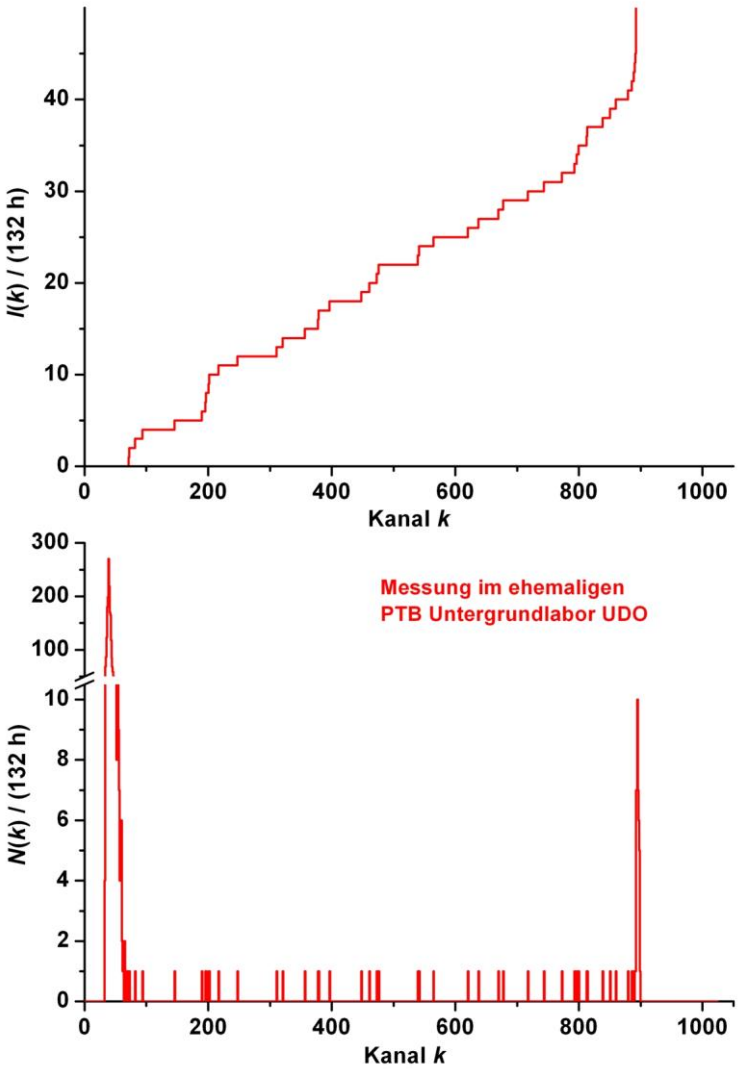

Fig. 3: Lower row: Pulse-height spectrum of an SP9 counter without external neutron radiation. Upper row: integral representation of the pulse-height spectrum with $I(k) = \sum_{i=1}^{k} N(i)$.

In this representation, from the slope of the curve, the detector-specific intrinsic background can be determined in the range where the neutron events usually are registered – all other parameters (signal amplification, etc.) remaining unaffected. Thus, a lower detection threshold for the neutron flux density can be indicated – and measured with the NEMUS spectrometer. Approximately half of the 17 tested detectors in total are, due to the count rates induced by alpha-decay, suited to perform measurements in a background with low neutron flux density. A quantitative analysis of the measurement campaign at UDO is in preparation.

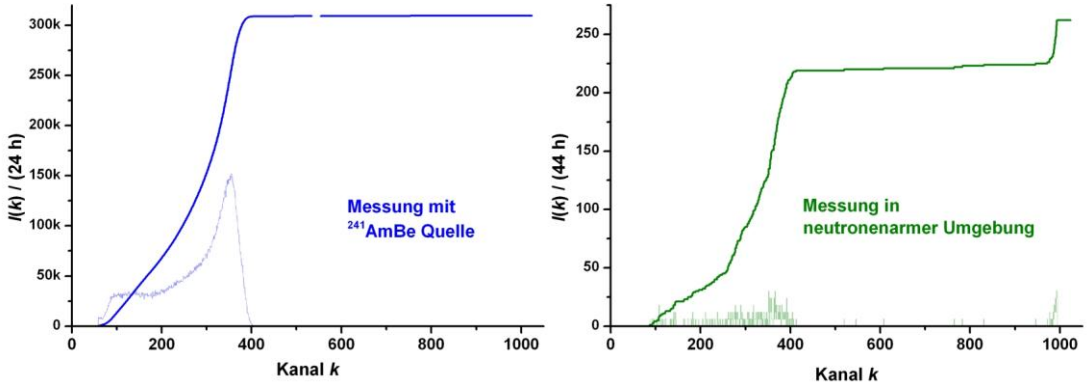

Fig. 4: Integral representation of the pulse-height spectra from Fig. 2 with $I(k) = \sum_{i=1}^{k} N(i)$. In addition, the pulse-height spectra are shown in standard representation (with light colours).

Figure 4 shows the integral representation of the pulse-height spectra shown in Figure 2 in the usual form. In the case of measurements performed in fields with high neutron flux density, the influence of the intrinsic background does not play a role (left diagram). The PHS shown in the right diagram of Figs. 2 and 4, resp., is the result of a test measurement at the underground measurement laboratory "Felsenkeller" of VKTA (Nuclear Engineering and Analytics) [5] near Dresden. The structures of the integral PHS seem to indicate an overlapping of "real neutron events" and of intrinsic background signals.

By means of a mathematical procedure that is being developed, the two shares of radiation can be separated in order to determine the neutron spectrum corresponding to the underground measurement laboratory "Felsenkeller".

Literature:

[1] http://www.ptb.de/de/publikationen/jahresberichte/jb2010/oe6/_nachrichten6.htm
[2] http://www.ptb.de/en/org/6/65/_index.htm and the references mentioned there.
[3] S. Neumaier; D. Arnold; J. Böhm; E. Funck: **The PTB underground laboratory for dosimetry and spectrometry.**; Appl. Radiat. Isot. Vol. 53 No. 1-2 (2000), ISSN 0969-8043, pp. 173-178.
[4] B. Wiegel, J. Wittstock: **Apparativer Nulleffekt von ^{3}He-Proportionalzählern in Bonnerkugeln.**; In: S. Neumaier, R. Zwiener, J. Böhm (Hrsg.) Experimente im Untergrundlaboratorium UDO der PTB im Bergwerk ASSE II, PTB-Dos-43 (2003), ISBN 3-89701-959-0, pp. 32-34.
[5] Verein für Kernverfahrenstechnik und Analytik Rossendorf e.V. (Nuclear Engineering and Analytics – VKTA)

Contact

B. Wiegel, Department 6.5, Working Group 6.53, e-mail: burkhard.wiegel@ptb.de