Joliot-Curie School 2014

Detection of Neutrons

R. Nolte, PTB, Braunschweig, Germany

The measurement of neutrons is complicated by the fact that they do not carry an electric charge. Hence, they can only be detected instantaneously by observing charged particles or gamma radiation emitted in neutron-induced nuclear reactions. Delayed detection is possible by measuring the radioactivity of the product nuclei. This is why neutron detectors, in contrast to detectors for charged particles and photons, are based on a large variety of construction principles. Actually, almost every radiation detector can be converted to a neutron detector by covering it with a converter in which neutrons produce the kind of radiation for which the detector was designed.
The range of neutron energies of relevance for nuclear technology, nuclear physics and neutron-based interrogation techniques ranges from the thermal point at 25.4 meV to several hundred MeV. The quantity of interest in neutron measurements is usually the number of neutrons per unit time, kinetic energy and cross sectional area perpendicular to the neutron momentum, i.e. the spectral neutron fluence rate.
Neutron detectors are best categorized along the energy range for which they are designed. In the thermal, slow and intermediate energy range, i.e. below one MeV, only exothermic reactions such as $^{10}B(n,\alpha)^{7}Li$, $^{6}Li(n,t)^{4}He$, $^{3}He(n,p)^{3}H$ or $^{235}U(n,f)$ can be used because of the small kinetic energy of the neutrons. In the fast and relativistic energy range endothermic reactions can be employed as well. The most fundamental process for the detection of fast and relativistic neutrons is elastic neutron-proton scattering with detection of the recoil proton. In the fast energy range between 1 MeV and 20 MeV, the differential cross section for neutron-proton scattering is known sufficiently well that it can be employed as the primary standard for neutron measurements. The most important application of neutron-proton scattering for the detection of neutrons is in organic scintillation detectors and gas proportional counters. In these detectors, the converter is also used to detect the charged reaction products while in other types of detectors, such as fission ionization chambers or recoil proton telescopes, the reaction products are detected in a separate medium. Neutron detectors based on the moderation of neutrons and subsequent detection of the thermalized neutron with high efficiency can be used over the entire energy range. They are, however, not well suited for problems requiring good time resolution because of the finite moderation time.
Due to the complicated process of neutron detection, the determination of the detection efficiency of neutron detectors is often carried out by 'calibration', e.g. by establishing a relation between the reading of the detector and the neutron fluence, as measured with a reference instrument. Such a calibration, however, is strictly valid only for the conditions prevailing during the calibration measurement and it is often difficult to transfer it to other experimental situations. This is why Monte Carlo based methods for calculating the detection efficiency directly from nuclear cross sections became more and more important. These methods make it also possible to include the influence of multiple neutron interactions and incomplete energy deposition consistently. In the relativistic energy range, however, the applicability of this approach is still limited by the need to model complicated neutron-induced breakup reactions with several

particles in the exit channels. Another problem arising in the calculational determination of detection efficiencies is the lack of data for properties of detector materials, such as scintillation efficiencies, ionization yields or the hydrogen content of organic substances.

Neutrons are almost always accompanied by other types of radiation, in particular by photons. This is a problem for neutron detection because neutron detectors are usually sensitive to other kinds of radiation as well. Hence, the capability to discriminate neutron-induced events from events induced by other particles is an essential feature of neutron detectors. Several techniques based on the analysis of signal waveforms were developed for this purpose using either analogue of digital signal processing.

The most powerful method for measuring the neutron energy distribution is the time-of-flight technique. This method requires a pulsed neutron source. In thermal energy range this is achieved by using mechanical neutron beam choppers. In the fast and relativistic range the time of neutron production is fixed by using charged-particle beams with pulse durations in the nanosecond range. The energy resolution achievable using this technique is determined by the duration of the beam pulse, the flight distance and the time response of the detector. In particular for the rather short flight distances available in most nuclear physics experiments, the detailed understanding of the time response of detectors is essential. Usually this is determined by Monte Carlo simulation together with the calculation of the detection efficiency. If a pulsed neutron source is not available, the neutron energy distribution must be inferred from the energy-dependence of the detector signal, e.g. from the pulse-height distribution of organic scintillation detectors. This technique, usually termed ‘spectrometry’, exerts strong demands on the accuracy of the detector response matrix and makes use of sophisticated algorithms to solve the so-called ‘inverse problem’. This technique can also be applied using a small set of integral detectors with significantly different energy-dependent response. Examples are activation foils or Bonner sphere spectrometers.

Quality assurance of neutron measurements is important to monitor the stability of neutron detectors because they often contain converters which can deteriorate in time. For the national primary reference instruments regular international comparisons are organized by the Bureau International de Poids et Measure (BIPM) in Paris.