Neutron Counting

Detector Applications Information Note

Neutrons are not electrically charged and will not create a signal as they pass through a detector unless they interact with the atomic nuclei of the detector material and create recoiling charged particles. It is these secondary charged particles that give rise to the scintillation pulse.

Detector Design Considerations

1. *What is the energy range of neutrons (E_n) to be detected?*
   - Slow or thermal neutrons E_n<0.5eV
   - Epithermal neutrons 0.5eV<E_n<50 keV
   - Fast neutrons E_n>50keV
2. *Is Neutron-Gamma discrimination required?*

   In most cases, neutrons are accompanied by gamma rays. These gamma rays may be emitted from the neutron source itself or be caused by neutron activation of materials surrounding the detector. Detector materials can be grouped into three categories according to their response to neutron and gamma radiation:
   - Sensitive to both neutrons and gammas, unable to distinguish which type of radiation has caused a given count.
   - Sensitive to both neutrons and gammas, but the type of radiation causing a given signal can be identified through further analysis.
   - Sensitive to neutrons, but insensitive to gammas.
3. *What type of output signal processing or counting circuit is required?*

   The output of a detector can be analyzed by several methods. Some of these methods are simple, while others are quite complex. To achieve full benefit from a detector, it is important to match the material's properties to the method of data analysis. Listed below are some of the most common methods. Each may be used independently or they may be combined with one or more of the others.
   - Low level discriminator (LLD) counting — all pulses above a selected threshold are counted.
   - Pulse height analysis (PHA) —a pulse height spectrum is acquired. In some cases, neutron events are grouped in a peak that can be separated from gamma events. In other cases, the neutron events form a continuous spectrum that must be unfolded to reveal energy information.
   - Pulse shape discrimination (PSD) – pulse shape analysis electronics are employed to sort detector pulses according to pulse shape. Usually this method is based on the decay time of the scintillator. This method is only applicable with certain types of scintillators.
4. Other considerations include signal amplitude and attenuation, time response and detector cost.

<u>Examples</u>

For each neutron energy group, some selected materials are recommended. The mechanism by which neutrons are detected is discussed; and where appropriate, the gamma sensitivity and counting system are noted.

Thermal (slow) Neutrons (<0.5 eV):

Low energy neutrons are detected by converting the incident neutron into 1 or more charged particles. When a neutron is captured, various charged particles are released and identified by the detector. The conversion is done by atoms that have a high thermal neutron capture cross section. The most useful atoms are ^{3}He, ^{6}Li, ^{10}B and Gd. Detectors containing the atoms are listed below. The Q value of a reaction is the excess energy that is imparted to the charged particles.

He-3 counters detect neutrons via the ^{3}He (n,p) T reaction. The Q value is 764 keV.

He-3 proportional counter efficient thermal neutron detection while being quite insensitive to gamma rays

^{6}Li loaded scintillators detect neutrons via the ^{6}Li (n, α) T reaction. The Q value is 4.8 MeV.

BC-702 ^{6}Li in a ZnS(Ag) matrix. 60% efficiency and very little gamma sensitivity. Employed in thermal neutron survey instruments.

BC-704 ^{6}Li and ZnS(Ag) matrix for thermal neutron radiography

GS-20, KG-2 Glass scintillators with high efficiency per unit area, 80% efficiency with little gamma sensitivity. 100% efficiency is possible with thicker materials and PHA.

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Neutron Counting

BC-523/ BC-523A Liquid scintillator with PSD capability

Gd loaded scintillators detect neutrons via the Gd(n,α) reaction. The secondary gamma rays create Compton scattered electrons which are detected by the scintillator. Because organic scintillators have low gamma stopping power, large scintillator volumes are recommended. The Q value is 8 MeV.

BC-521 Solvent-based for high light output

BC-525 Mineral oil-based for good light transmission.

Epi-thermal neutrons (0.5 eV to 50 keV):

Increased detection efficiency is achieved by moderating the incident neutrons to thermal energies and using one of the capture reactions. BC-702, and BC-704, He-3, and glass scintillators require an external moderator. The presence of hydrogen in the plastic and liquid scintillators allows the scintillator to serve as a moderator.

NP detectors Lithium loaded glass scintillator with a moderator packaged in a ruggedized housing.

Fast neutrons (>50 keV):

Detection is through (n,p) or (n,d) elastic scattering. Above 10 MeV, elastic and inelastic scattering reactions from carbon may provide detectable signals. Because they are composed of hydrogen and carbon, all organic scintillators will be sensitive to fast neutrons. A few types of particular interest are listed below along with their most common applications.

BC-720 ZnS(Ag) loaded, fast neutron survey instruments

BC-408 Plastic scintillator, n-sensitive monitors, neutron TOF

BC-436 Deuterated plastic scintillator, n-d scattering

BC-501A Liquids, high light output, PSD capability

BC-519 Liquid, mineral oil based, good light transmission, PSD capability

BC-521/BC-525 Gd loaded liquids, neutron spectrometry

BC-523/BC-523A Boron loaded liquids, PSD capability, neutron spectrometry

High temperature neutron counting applications

Gas-filled detectors, especially He-3 proportional counters, are well-suited for high-temperature applications.

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