# Neutron Detection Principles

Intro

Conversion Material

Solid-state (Semiconductor) Detectors

Gamma interference

**Intro**

This chapter briefly introduces the principles of neutron detection. Although many of the concepts apply to neutron detectors in general, the chapter is heavily biased towards gadolinium-based semiconductors.

The principle on which the detection of charged particle is based also applies to the detection of neutron. The process of ionization is the key factor in signal generation. A charged particle incident upon a particle detector induces a signal. Inside the detector the incident particle traverses the active volume and generates charge carriers by effects of ionization.

Particle detectors are also used to observe neutrons. However, the neutrons lack of charge poses a problem. Lacking ionizing features, a neutron is invisible to charged particle detectors. It simply penetrates the device without generating any charge carriers. In order to be observed, neutrons must first be converted into detectable particles. This can be done by introducing a neutron sensitive material to the detector design. Through neutron-induced nuclear reactions, the sensitive material, also referred to as conversion material, converts neutrons into secondary particles. In turn the secondary particles transfer energy to the active volume, indicating the neutrons presence. Although neutrons are not ionizing themselves, they are capable of inducing the production of particles who are, and in that sense, they are considered to be indirectly ionizing.

An arbitrary particle detector

* Active diodes
* Charge collection
* Diode?

**Choosing the appropriate conversion material …. Conversion** **Material**

Nuclear reactions?

X.S

In neutron detection, the appropriate conversion material must satisfy certain physical and nuclear criteria. For efficient neutron detection, the material must be sufficiently sensitive to neutrons. This ensures a higher percentage of detected neutrons. A large reaction probability (cross-section) also reduces the amount of conversion material needed, which reduce material expenses and enables for smaller detector designs.

Q-value

Another desirable feature is a high reaction-energy (Q-value). Neutrons interact with nuclei of the sensitive material and the nuclear reaction releases energy. With a high reaction energy, more energy is available for the product particles to gain as kinetic energy. Neutrons are often accompanied by gamma-rays. Gamma radiation infiltrates the neutron environment and interferes with measurements. A high reaction Q-value makes it easier to discriminate neutron-induced signals from gamma-ray induced signals, using *pulse-height discrimination techniques*. Also, with ample Q-value the secondary particles gain enough kinetic energy to reach the detectors sensitive volume and deposit a meaningful amount of energy that exceeds the detection threshold. [Glenn Knoll]

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In theory, this means that neutron detectors can be constructed by coupling a conversion material with an arbitrary particle detector. What distinguished the

Active volume

One of the major components of a detector is its active volume. The active volume is responsible for sensing ionizing radiation; it is here signal inducing charge carriers are generated.

The size of the active volume plays a role in signal quality. To achieve clear measurements the volume dimensions must be large enough such that signal generating particles can deposit all their energy to the medium. A particles' range is dependent on its kinetic energy and the material which it traverses. In the same material, more energetic particles travel further. If they are too energetic, such that their average path length in the material of which the volume composites exceeds the dimensions of the sensitive volume, only a fraction of their total kinetic energy is transferred to the medium. Insufficient energy transfer leads to poor signal quality. It is therefore essential that the active volume completely encapsulates interacting particles.

In gas detectors the active volume is intuitively filled with gas and in semiconductors a solid material fills the volume. Scintillators may incorporate material of either gas, liquid or solids, depending on detector application and requirements.

Depending on the type of particle detector, the sensitive volume can be made out of/filled with a gas, a liquid, or a solid. Particles travel further in gases than solids. For this reason, gas detectors require a larger sensitivity volume than solid-state detectors to capture particles of interest. Electrons, for instance, **travel ... In He which is nearly ... Greater than in silicon... Rewrite**

…. Fortsett her. Pros of solid state compared to gas. Compact, cheap, radiation damage?

**Define peak amplitude**

Combining a particle detector with the appropriate conversion material makes it possible to study neutron flux of interest. Three basic types of particle detectors are the gas-filled detector, scintillation detector and semiconductor detector. All in which ionizing effects are responsible for generating charge-carrier and subsequently a pulse signal. Gas detectors are intuitively filled with gas

In gas detectors the sensitive volume is intuitively filled with gas. The volume is usually confined by a cylindrical chamber wall. An ionizing particle traversing the volume generates electron-ion pairs, charge carriers of the device. The chamber wall is … charged and acts as a cathode(?) and inside the chamber is typically a rod-shaped anode. The charge carriers drift towards and are collected by respective electrodes, ions towards cathode and electrons towards anode. The charge collection process generates a signal in the detector. Because of their inherently small mass, electrons are accelerated and collected more quickly than their much heavier ion partner. Complete charge collection is … for good signal quality. Gas detectors are therefore generally much slower and/or more unreliable than solid-state detectors which practice much more efficient charge collection (which will soon become apparent).

**In the field of neutron detection there are many different combinations of detectors and conversion materials, each designed with a specific task in mind.**

**BF3 filled gas counter, scintillator, There are many different**

**Gadolinium-Based Semiconductor Detector**

**Gamma interference**

Poses as a problem for both gas and semi. Gas BF3 counter, gamma produce electrons. In gd based semi, produce x-rays. Explain the pile-up. Time constant. Incomplete charge integration.

**Main focus:** gd based semi. E.g. also applies for other detectors such as BF3 gas

Gamma-rays often tagg along with the neutron flux of interest(?). Gamma-rays have a low probability of reacting with matter, especially in comparison with charged particles, and if they do interact, the resultant energy transferred is generally insignificant. In BF3-filled gas counters, gamma-rays interfere with the counter walls and produce secondary electrons. These electrons proceed to the active volume (which is filled with gas) where they deposit a fragment of their total kinetic energy. The result is a small **peak** **amplitude.**

**( ! )**

A similar effect can be observed in solid-state detectors. Because solids hold a larger stopping power than gas, solid-state detectors are much more compact than those filled with gas. The probability of an energetic gamma-ray is slim in thin ….

In radiation environments with low gamma-ray flux the interference of gammas are easily dealt with. However, when the presence of gamma-rays becomes increasingly noticeable the number of interactions in the detector occur more frequent and can lead to pulse pile-up. A multitude of gamma-rays interacting with the detector within a small time frame () appears to the detector as a single event, where the deposited energy is the sum of the collective energy transfer. The pile-up effect leads to an **apparent peak amplitude**. The gamma induced pile-up signals can come to interfere with those induced by neutrons.

The adjustable timeframe during which a detector integrates the generated signal is called the integration time. To minimize the effects of pulse pile-up, one can shorten this time frame such that gamma-rays have less time to interact with the detector and the apparent amplitude becomes less of a threat.

The detectors signal integration time can be adjusted to adapt to such interference. A shorter time constant means less gamma rays have time to interact with the detector and thus the apparent peak amplitude will not be as significant. However, a shorter charge integration time also imposes the problem of incomplete signal integration for the neutron ….

1. Sufficinet AV 🡪 particle deposits all energy (?)
2. Sufficient AC 🡪 Full RP energy peak, noise (left)
3. Infufficient AV 🡪 continuoum, not all energy is deposited.

A close up of a mans face

Description automatically generated A close up of a map

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# Old

**Intro**

This chapter covers slow neutron, active, indication (not energy)

There are many different types of neutron detectors. This thesis project looks at an active semiconductor detector sensitive to thermal neutrons. Gd based silicon semiconductor. The detector only registers neutron presence and does not reveal other types of neutron information such as kinetic energy. The current chapter will therefor cover the fundamentals of neutron detection with focus on thermal-neutron indication.

Neutron detection methods are very similar to those of regular particle detection. In particle detection, ionization is fundamental. It is the process responsible for producing a signal, by generating electric charge in the detectors sensitive volume.

The critical difference between charged particle and neutron detection is a neutrons lack of electric charge. Neutrons, in contrast to electrons and ions, are chargeless and are for this reason, uncapable of ionization. They can, however, induce ionizing radiation by interacting with a neutron sensitive material which converts neutrons into charged particles. *Though not ionizing themselves, neutrons produce particles who are, and in that sense neutrons are considered to be indirectly ionizing. [Klett 2012]* Coupling a conversion material with a particle detector enables the essentially neutron blind device to see neutrons.