

## Modern detector concepts for fast-neutron radiography

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The topic presented is part of a project called periodic testing by imaging with neutrons in addition to X-rays (PERTINaX) which has started in November 2016. The project is funded by the Federal Ministry of Economic Affairs and Energy (BMWi) under the funding code 1501534 and continues work and research done in the project neutron imaging system for radioactive waste analysis (NISRA) [1], which was funded by the Federal Ministry of Education and Research (BMBF).

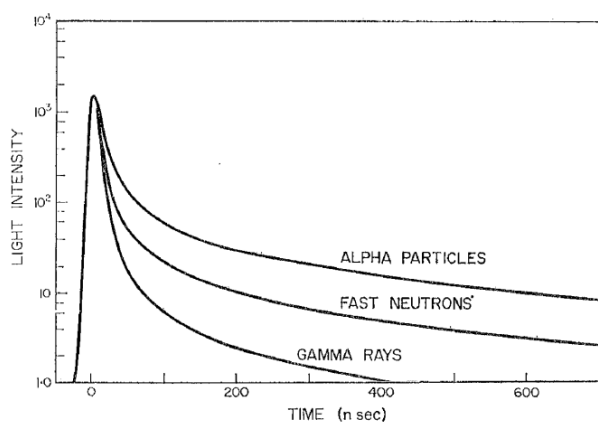
The aim of the PERTINaX project is the development of a mobile fast-neutron radiography system which can be combined with neutron activation analysis for non-destructive testing of high-density and shielded components.

Due to the high probability of interaction of neutrons with hydrogen, neutron radiography in combination with neutron activation analysis can be used to detect local accumulations of water, which is important especially in nuclear facilities respectively nuclear power plants.

### Scintillator materials

The major challenge of PERTINaX is the development of a detector system that offers sufficient spatial resolution. Different scintillator materials as well as different detectors for scintillator read out come into consideration.

In an environment where  $\gamma$ -radiation is present,  $\gamma$ -fogging of taken neutron radiographs can occur if the detector system used is also sensitive to  $\gamma$ -radiation. Many scintillators can distinguish  $\gamma$ -radiation from neutrons. Therefore, they are suitable for application in neutron radiography. Organic scintillators like trans-stilbene or liquid scintillators, e.g. EJ-301 from Eljen Technology [2], allow pulse-shape-discrimination (see Figure 1) which can be used for this purpose.



**Figure 1:** Scintillation decay for  $\gamma$ -rays, fast neutrons and  $\alpha$ -particles in trans-stilbene. Intensities normalized at  $t=0$  [3].

Due to the difficult machinability of trans-stilbene, stilbene-compound scintillators (investigated by Seung Kyu Lee et al. [4]) could be used to simplify the production of scintillator arrays.

In order to achieve spatial resolution using liquid scintillators, matrices consisting of thin glass capillaries could be filled which would lead to a scintillator comparable to a scintillator array out of solid material.

### Detectors for readout

Applying pulse-shape-discrimination requires detectors which can provide timing information. Since spatial resolution is also required to perform the radiography, detectors which combine these properties have to be chosen.

Multi-anode photomultiplier tubes which are used in positron emission tomography (PET) etc., silicon photomultiplier arrays or even digital silicon photomultipliers, which are relatively new and at the moment not yet commonly used like other detectors, are suitable for this purpose.

Depending on the number of cells or pixels which have to be read out, appropriate electronics (e.g. based on FPGAs) that is able to observe a large number of channels must be used.

### Combined techniques – neutron radiography and neutron activation analysis

Structural information about the specimen to be investigated gathered by neutron radiography, e.g. in addition a complementary radiography based on  $\gamma$ - or X-rays allows specification of geometry and homogeneity. The presence of radiation shields or hydrogen-containing substances inside a closed barrel leads to large uncertainties for the neutron activation analysis.

Once these materials and geometries are known, their influence on different parameters ( $\gamma$ - and neutron- self-shielding factors, neutron flux, etc.) can be considered to improve the results of the neutron activation analysis.

- [1] J. Kettler et al., *NISRA Abschlussbericht*, 2015.
- [2] <http://www.eljentechnology.com/products/liquid-scintillators/ej-301-ej-309> (Dec 2016)
- [3] J.B. Birks, *The Theory and Practice of Scintillation Counting*, Pergamon Press Ltd., Oxford, 1964.
- [4] Seung Kyu Lee et al., *Scintillation Properties of Composite Stilbene Crystal for Neutron Detection*, in: Progress in Nuclear Science and Technology, Vol. 1, 2011, pp. 292-295.